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End of Project Report

NEW-EIR, UV-C AIR STERILIZER

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EXECUTIVE SUMMARY

Elevator Pitch - New EIR, Germicidal UV-C is an easy to install device to monitor your indoor air quality and sterilize airborne pathogens like influenza and coronavirus, improving indoor air quality.

Indoor air quality is a major factor in everyday life and comfort. The air that humans experience indoors is filled with more than just the oxygen we need; it carries with it volatile organic chemicals, Particulate matter, combustion by-products, and airborne pathogens. Hospital HVAC systems are designed to prevent the spread of the pathogens as well as to filter out all other harmful air pollutants. Hospitals spend millions of dollars yearly to ensure safer air is keeping the patients safe from more harm. Air pollutants are more easily found concentrated indoors and the HVAC system set up at hospitals is the main way to curb their effects.

An HVAC system can change the quality of air, dependent on the cost, to near all degrees. What has also begun being used is the addition of UV-C light within HVAC systems in order to help in the lessening of air pollutants. At specific wavelengths, the UV-C waves can destroy the surface proteins of viruses and other airborne pathogens including bacteria and mold in a safe way with non harmful by-products. New experiments have shown that UV-C lights can kill the COVID19 virus within 5 seconds of exposure. The most dangerous pathogens that are most common in hospitals as well as everyday public areas can be killed by UV-C light.

The addition of an GUV (Germicidal Ultraviolet light) into an HVAC system is a usable form of sanitation for harmfull lung disease fungi, bacteria and viruses when used over extended periods of time. Areas within HVACS where heat and moisture collect naturally grow bacteria and fungi. GUVs eliminate this growth. Hospitals experience these effects as well, named HAIs. Poor air filtration and sanitation is a major cause for healthcare associated infections and it is understood one would be equally or more likely to experience them outside of a medical setting. The hospital budgets have shown an increase in funding to combat more HAIs as the further mutation and increase in global temperatures bring with it easier breeding grounds for pathogens to emerge.

COVID19 is an example of a pathogen that needs to be mitigated on the level hospitals attempt to do in order to slow its spread. Its form of spreading has made it difficult to contain and has caused massive shutdowns of global economies to attempt to slow its spread. Most economies felt the impact of the virus already. Quarantine shutdowns, mask mandates, and outdoor only events for businesses have halted regular business, school, travel and leisure. Many countries have injected emergency funds into strategizing for small businesses on how to remain safe but also stay open in order to not further the health crisis into a financial one. The United States has already begun seeing major effects as 67% of businesses closed during the pandemic will not reopen.

The challenge being faced is creating a safe and cheap way to help businesses, schools, and public spaces with enclosed areas remain safe and open. The cost would need to be lower in order to help as many people as possible in as many areas as possible. Pandemics like the one occurring and future ones need to be combated now with low cost, effective forms of sanitation that allow for the most effective preventive measure to combat airborne pathogens and pollutants.

The on-set and rapid spread of COVID-19 throughout the world prompted shutdowns of schools, businesses, churches, restaurants, movie theaters, and many other places that provide necessary employment and enjoyment for people. One major vector of virus transmission which prompted these mass shutdowns is virus transmission from unsanitized air circulating within a building. Billions are spent on commercial HVAC systems that are designed to filter, dehumidify, cool, and heat an occupied space to a comfortable level however, these systems rarely include processes for sanitizing that air. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) states that “indoor air quality (IAQ) … [is] known or suspected to affect people’s comfort, well-being, health, learning outcomes and work performance.”. HAI’s cost U.S hospitals billions of dollars anually. COVID-19 and other infections including tuberculosis and norovirus are transmitted via air and can cause mass infections at hospitals. Isolation rooms for highly contagious patients have HVAC designed to exhaust contaminated air. However, sanitizing other areas of the hospital, especially communal areas like hallways and waiting rooms, often do not have this capability of preventing contamination. In other commercial operations that have remained open such as grocery stores, asymptomatic individuals potentially contaminate the circulating air and other customers. Businesses being unable to operate virtually will heavily impact the economy due to mass unemployment and loss of business. Businesses need clean, healthy air to prevent the spread of infectious airborne diseases so they can remain open for business.

To solve the problem of sanitizing air especially for hard hit businesses, Team 14 devised an easy to install module that can be incorporated into existing HVAC systems. The designed system will track and monitor indoor and outdoor air quality. The main device will be inserted into the ventilation ductwork to sample the indoor air quality, while a remote device will sample outdoor air quality. The team has researched germicidal UV-C and its effectiveness at sterilizing microbes. The team designed a UV-C lamp inderted into the ventilation air flow to irradiate the air before being circulated back into the occupied space. HVAC components like evaporator coils have had many issues with promoting the growth of dangerous microorganisms. The device can be installed at either the air in-tack before the evaporator coil to sterilize microorganisms on the coil or in the supply distribution part after the air handler unit to distribute residual hydrogen peroxide disinfection to the occupied space. At both locations, the indoor occupants are not exposed to UV radiation and the installer is safe from dangerous mechanical and electrical hazards of the HVAC system. UV-C lamps can operate when the indoor air quality sensor registers high levels of TVOCs, which cause unpleasant odors and toxic pollution in the air. The UV-C can neutralize VOCs from the incoming and interior circulating air. This apparatus will be more cost effective than replacing an entire HVAC system. It will incorporate the same UV-C technology for air sanitation currently being used in sterilizing surfaces.

Using UV-C light to disinfect the air as it circulates is a key part to keeping airborne disease transmission at a minimum. Ultraviolet light is used as germicidal irradiation (UVGI) to reduce the prevalence of the microorganisms. Ultraviolet-C (UV-C) lighting in the central ventilation can effectively improve IAQ by destroying microbes and neutralizing air pollutants under normal HVAC operating conditions, allowing healthcare facilities, schools, and businesses to be open to indoor operations in a safe, healthy, and productive environment. A solution for HVAC systems currently is to add the UV-C lighting while minimizing the power and cost to do so by making it power independent. A UV-C lighting module that can be fitted to current building HVACs will cut down on UVGIs, potentially reducing HAIs, maintaining efficiency while its energy independence feature removes the need and cost of HVAC replacement as well as allowing it to be used in a variety of various locations.

The project design had the worldwide market as a key driving thought for the cost. In an international market, the costs of the parts would need to be small enough to be available to areas with little funds, same as the funds the team had available. The idea of this project is to have an affordable UV-C air sterilizer, so our goal is to find inexpensive parts effective in sensing necessary safe and sanitizing metrics. The parts for this workable prototype will be self-funded by members of the team. By the end of semester, the project will have a workable prototype that monitors air quality, operates a UV-C lamp, measures the UV-C output, and reports relevant information to a mobile app. The final product we will be designing in the spring will be pricier as it includes an independent power source. The PV solar array and back-up battery supplying the power will be the largest expense.

To successfully implement the listed features a workable timeline was needed. The team came together and formed a project timeline that accounted for all the delays the system could suffer as the design was fleshed out. The project timeline follows the Work Breakdowns Structure, allowing for easy information and next step verification. The timeline goes through all aspects of the project: team creation, positions, research, report part assignments, features and tasks. The timeline gives a clear view of the pace the project needs in order to be prepared at the correct time as well as give extra time for issues from testing ,to be addressed.

The timeline has several sections to simplify organization. The first section is the weekly assignments accomplished in the early months of the project that involved team creation, research, and weekly assignments. Most of this section occurs in the early August and September sections of the project timeline. The next section deals with the project report. It shows each subheading for the report and future sections allowing for a solid plan that the team can follow. The last section is for the project build tasks. It is divided into 4 sections as the project naturally is divided as such: indoor, outdoor, software, and mobile application. This work was divided amongst the team members and a time line was created with date estimations on when each part should be done for us to have a finished product on time.

The time line organized the project in such a way that allowed for the division of labor into its main parts. Each team member had a say in the feature and part of the project they would most heavily influence. The design for the project involves the creation of three parts: an indoor and outdoor part, as well as the phone app. The outdoor components will feature a main board set up as the hub for all sensor data compiling, light control, and communication with the app. The board will take in data from the sensors from both the shaft of the HVAC system as well as outdoors. The main board will be programmed to take in and send data, and control the UV bulb. The outdoor feature will include its own sensors, a battery and the solar panels attached.

The indoor feature is the crux of the project. It has the UV lamp for the sanitation, the sensors to monitor the levels of UV-C light and air quality and the housing for it all. These components will have the most consideration made over them as they will be the driving feature of the design. The addition of a second bulb will be deemed necessary after sensor data for UV-C lighting on the heat converter of the HVAC system will.

The second set feature si the outdoor components. These include air quality sensors, the solar panels for power and the battery back up. The panle and battery combination was fleshed out in the second sememster of the project as its functionality would only be necessary once the indoor parts operated with no issues. The time line shows this consideration and is less important than the last feature.

The last feature is the app. The app that the user of the product will have can control the light itself, will send the air quality information to the user and allow for settings to be placed for automated running of the bulb as set by the user. The app will alert users of certain air level measurements the user can have set. The ease of use and functionality of the app is paramount to the function of the app.

The work will be centered around finding the key features (UV bulb, controller, sensors,.etc) first. The power and batteries will be the last of the tasks as we will be testing the product with continuous power first. Team members with strengths in code and app development will create the app along the period of the sensor acquisition.

The discussion of the work breakdown allowed for the risk assessment to be easily be brainstormed. The numerous team meetings allowed for the risks to be easily brainstormied. All projects will have events that delay and pause any progress being made. This event can be unpredictable or predictable with intuitive foresight and planning. Experience can help know what to expect with better probability but we have to rely on communication instead. A team must be prepared for all eventualities that come with the specific project and its parts. The risk each delay holds can be seen as having a higher or lower chance of occurring as well as its potential to cause delays to the project. The section dives into the explanation of the risks our team has found that will occur with the project, their likelihood of occuring, the delay potential of that risk, and the plans made to mitigate the events if they were to occur.

The chart used in the section presents a clear organization of the risks the project holds. The color coding allows for a graphical representation of the severity of each event and its effect on the progress of the project. Both the chart and the explanation will be used as a reference for the team and answer any questions a reader would have exploring the project's processes. The section covers the effects and plans to deal with social distancing, as required by the university and state, member burnout, part and component compatibility, code issues, and even COVID-19.

Once the team had moved through the design and its risks, the work and feature assigned to each member ,the progress on the project was inmense. A new task was deployed to one of the members to do updated reasearch on the current use of the technology, UV-C, being used. As the system we made was coming together , it was undestood that we had a solid usable product design. Boston University School of Medicine has tested UV-C germicidal effects on SARS-CoV-2 and found it capable of eliminating more than 99.9% of Coronavirus in 5 seconds in a dry environment. UV-C lamps can be installed inside HVAC systems without interference with the system's operation. Inside the system, UV-C can sterilize the ducts and sanitize the air passing through it. One of the UV-C by-products is hydrogen peroxide, which can be distributed through the ductwork and building to further disinfect contaminated surfaces.

We have tested UV sensors and air quality sensors used for our prototype. To confirm correct dosage, a UV sensor will measure the UV output. We tested and found the UV sensor to be fully accurate. The outdoor sensor was also accurate at measuring temperature, humidity, and air pressure. The air quality index readings were found to be decently accurate, with the limiting factor being that our device does not consider particulate matter when it calculates the air quality index. Other than that, the air quality readings were accurate to the expected result. The indoor air quality sensor will tell how much CO2 and TVOCs ar e in the air and the sensor was accurate to the manufacturer's specifications. Tests show that UV-C reduces the measured TVOCs in the air, but prolonged use in small, occupied areas lead to false readings. We found this to be caused by UV-C's byproduct, hydrogen peroxide. We ended up replacing that sensor that lead to the false positives with another sensor that was tested and found to be a more reliable indoor air quality sensor. Both sensors can be used to measure TVOCs, CO2, and UV-C by-products.

With all the sensors working as intended and proven to be able to detect the necessary things within the predefined limits, we moved on to testing the mobile app. The tests for the mobile app were simple. The first test was to verify that the application would load on a mobile phone, which was a success. The second test was to be able to display data on the screen and change it, which failed initially due to incorrect function calls that allowed the app to compile, but when it came to running, they resulting in nothing changing on the screen. Once this issue was resolved, the app was then tested three additional times to ensure that it was able to connect to a Google Sheets file, read the data that was displayed on there, and finally take it and display it for the mobile app user to be able to read at their leisure. This too proved to be a success. However, this part of testing was the most problemtatic and over half of the development time was spent resolving this one issue.

The difficult problems were fixed and tackled by a few of the team members, leaving the others to work on the marketability of the design. The research done midway through was to see how far along the current market for UV light sanitation products was. The market for our UV air sterilization is defined by the scope, which will start locally, but could reach internationally due to the virus control and vaccine accessibility around the world. We will target small businesses and large public buildings, such as schools, gyms, etc. The people in charge of making the purchasing decision will usually be over 45 years old and unfamiliar with the technological concepts involved in the product. There are companies who have been providing comparable products and services successfully for years, however we will serve clients with a lower budget, as there will be a large price disparity in our services. The market is wide open because of the sharp increase in demand, and there are no companies that currently dominate the market. Tests have already shown the market is expected to expand due to the applications in public institutions and growth opportunities for regional and local players also exist as they target low-priced products.

We plan to reach the local market by creating a website and gaining trust with our potential clients. We are mostly inexperienced students, and our perception will be an obstacle to overcome when established companies already exist. We will need to explain the problem of pathogens spreading within a building just as well as we explain how our product can prevent it and keep people safe. Consumers are still learning about the spread of airborne disease and will be looking for reliability to keep their building clean.

Abstract

The recent pandemic has devastated global small businesses, schools, and public events. The inability of these areas to safely remain open to continue to function has affected the entire globe and has touched most areas of the population. The economic toll will continue if no measures are put into place that allow for cost effective sanitation off both the air and the surfaces. The best way to accomplish both can be done using UV-C light at a specific wavelength. The implementation of UV-C light within a buildings HVAC system can clean and sanitize the entire duct system from AIQ and airborne pathogens while produce hydrogen peroxide that is funneled through that system, sanitizing surfaces that it lands on. UV-C kills harmful pathogens and bacteria while producing safe sanitation surfaces. The NEW EIR device easily installs into already installed systems, at a low cost to businesses and public access areas, producing maximum safety with minimal invasiveness. It will also allow for the user to monitor the AIQs of the local area and show the difference between the values indoors from outdoors. This leads to the design of the project.

The design of this problem-solving project uses Ultraviolet-C lighting in a central ventilation unit of a small home or business to improve Indoor Air Quality (IAQ) by destroying infectious diseases and eliminating indoor air pollutants. Team 14’s design is an attachment to installed HVAC systems tracks and monitors indoor and outdoor air quality and utilizes UV-C technology for air sanitation. It contains three key features: the light itself, the monitoring app for the sensors, and the power source. The decision on each part choice is discussed at length as we kept the lack of our own funding in mind as well as the cost those who would use the product would have available. The section also discusses the thought process for handling and placing the UV light within the system as we researched the cost of HVAC renovations. It discusses the minimum requirements the team set as to both be functional and be within the scope of our knowledge. We are only limited by the funds we have, but plans had been made early on for usage of a loan to allow for stress-free parts purchasing for the larger pieces of the system.

The idea of this project is to have an affordable UV-C air sterilizer, so our goal is to find inexpensive parts effective in sensing necessary metrics. The parts for this workable prototype will be self-funded by members of the team. The student loan used covered the cost of the large panels and battery testing, along with other components needed for the power such as testing several charge controllers for the solar panels. The testing of the components together on the sensor/UV light side was more straightforward and costs were well-estimated while power costs became a growing number as more, new data was used to attempt to fulfill the tasks within the timeline.

The costs and research led to the creation of the timeline section early on and allowed for a flow of work needed to stay on point. The timeline shows a breakdown of the project progression including specific deadlines, supply/part acquisition, assembly of prototype, testing and analysis, etc. in a visual format. The team used constant contact to keep the project timeline in mind and on schedule. This section also will show the milestones the project had: larger achievements, such as the formation of the team, the selection of the design problem, and the beginning of testing. It was made more detailed in the next section.

The work breakdown structure was naturally formed from the way our idea developed early on and this section shows that. Project tasks are broken down into smaller units under the three main components of the overall design: indoor components, outdoor components, and the graphic user interface. The general task management of each part of the project is presented and given dates and team member assignments which can be followed on the Gants chart as well. The separation of work led into the risk assessment section and how to handle its creation.

The work assigned along with the timeline gave us the details needed to create the risk assessment section and the chart to clearly show the events that would delay and even jeopardize the entire project. The team has brainstormed the delaying events the project may have to the deadline, their likelihood of occurring, (from social distancing

to component issues and design flaws) and the plans that are in place to not allow it to change the finish date nor change the timeline. Each member contributed to the feature they worked on and jumped into other sections when no could be thought of. The section goes through the likely to unlikely events as well as each events effect on the time for getting the project out in time. The assessment was used to maintain the schedule put down from the previous section to put out the deployable prototype using our groups design philosophy.

The project had momentum that never died out for the team. The selection of the design, the team dynamic, and the drive to get the project finished kept us moving forward. We chose to always focus on the function for the consumer of our clients as well as the purchaser of the product themselves. The app was for the control of the sensor data but also was able to make data available via QR code. The ideas driving the project were the global market versus the national market. These driving ideas allowed for the timely of creation of the prototype.

The system needed several tests to fullfil the minimum of our measurable metrics. The sensors where first tested to ensure they were effective and reliable at measuring UV light and air pollutants. Then they were used to test how effective and reliable UV-C was at removing hazardous indoor air pollutants in the design idea prototype. Additionally, we were able to get those readings from the tests onto a Google Sheet file and read them from our mobile app, confirming it works. The power feature of the project was tested as well. The UV-C bulb was able to be powered for 24 hours showing that the battery had retained its charge as well.

New EIR is marketable as a low-cost air sanitization unit that is targeted at small businesses and schools. The market is small and relatively new, but there are some competitors who have been in the industry for up to twenty years. The pandemic has increased the demand for this type of product, creating room for newer businesses to establish themselves.

Keyword Index

Airborne diseases, COVID-19, Disinfection, Efficiency, Healthcare-associated infections (HAI), HVAC, I2C, Indoor Air Quality (IAQ), indoor pollution, microcontroller, Mobile App, UVGI, UV-C, Volatile Organic Compounds (VOCs)

I. INTRODUCTION

The on-set and rapid spread of COVID-19 throughout the world prompted shutdowns of schools, businesses, churches, restaurants, movie theaters, and many other places that provide necessary employment and enjoyment for people. One major vector of virus transmission which prompted these mass shutdowns is virus transmission from air circulating within a building. Billions are spent on commercial HVAC systems that are designed to filter, dehumidify, cool, and heat an occupied space to a comfortable level. However, these systems rarely include processes for sanitizing that indoor air.

The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) states that "indoor air quality (IAQ) … [is] known or suspected to affect people's comfort, well-being, health, learning outcomes and work performance." The ability to sanitize circulating air and/or exhaust contaminated air is especially crucial in medical facilities, which are one of our most essential services and already have an elevated risk of healthcare associated infections (HAI). HAI annually cost U.S. hospitals billions of dollars. COVID-19 and other infections including tuberculosis and norovirus are transmitted via air and can cause mass infections at hospitals. Isolation rooms or wards for highly contagious patients have HVAC systems designed to exhaust contaminated air; however, sanitizing other areas of the hospital, especially communal areas like hallways and waiting rooms, often do not have this capability. Without proper ventilation of clean healthy air in hospitals, contaminated patients may continue to infect hospital workers or other hospital patients. Hospitals have used ultraviolet light to effectively sterilize pathogens on instruments, surfaces, and indoor circulated air. UV light in the C bandwidth can damage microbial pathogens' DNA rendering it incapable of reproducing and infecting humans. UV-C does not just disinfect or sanitize by only killing or deactivating 99.99 % of microbes it sterilizes by eliminating all forms of viruses, bacteria, fungi, and their spores. UV-C is a sterilization method that does not require safe storage nor does it contaminate the air with volatile chemical by-products like ammonia or chlorine. The intense energy of UV-C can break down volatile organic compounds produced by microbes and common chemical cleaning products.

When installed in HVAC ventilation UV-C sterilizes the air without exposing humans to UV radiation. UV-C has been an effective way of reducing cross contamination and infections in hospitals, but COVID-19 is actively spreading outside of hospitals and health care facilities. Other essential services that have remained open such as grocery stores, have potentially asymptomatic individuals unknowingly contaminate the circulating air and infecting other customers. Non-essential businesses and services unable to operate virtually have been ordered by the governments to shoot down their operations during lockdowns across the globe. The mass unemployment and loss of businesses has heavily impacted the economy. Essential and non-essential businesses need clean healthy air sterilized by UV-C to prevent the spread of infectious airborne diseases so they can remain open for business.

Team 14 is proposing the design of an easy to install module that can be incorporated into existing HVAC systems. This equipment will track and monitor indoor and outdoor air quality. part of the equipment will need to be installed remotely to sample outside air quality. And part of the equipment will need to be inserted into the ventilation ductwork to sample the indoor air quality. The team has researched germicidal UV-C and its effectiveness at sterilizing microbes. The team will design a way of also interesting a UV-C lamp into the ventilation air flow to irradiate the air before being circulated back into the occupied space. HVAC components like evaporator coils have had many issues with promoting the growth of dangerous microorganisms, because of the moisture condensation inside it is tightly packed heat exchanger fins. There are two ideal locations for the UV-C lamp. For system sterilization and efficiency, installing the lamp after the air filter and before the evaporator coil to irradiate the broad surface of the coil will sterilize microbes on the surface of the coil and in the air passing through. For germicidal sanitation of a room the ideal place for installation would be in the main duct after the furnace. This is so that the residual hydrogen peroxide disinfectant is distributed directly to the occupied space. At both locations, the indoor occupants are not exposed to UV radiation and the installer has no need for entering the furnace compartment or air handler unit housing dangerous mechanical and electrical hazards of the HVAC system. UV-C lamps can operate when the indoor air quality sensor registers elevated levels of TVOCs causing unpleasant odors and toxic pollution in the air. The UV-C can neutralize VOCs from the incoming and interior circulating air. This apparatus will be more cost effective than replacing an entire HVAC system. It will incorporate the same UV-C technology for air sanitation currently being used in sterilizing surfaces.

To make the equipment operation easy to control for the user an app can be programmed for use on a smart device. The app can show air quality and activation of the UV-C lamp. A UV sensor can report on the intensity of the light and use of it for health officials to know that germicidal UV-C has been used at proper dosage during occupation and business hours.

By the end of semester, the project will have a workable prototype that monitors air quality, operates a UV-C lamp, measures the UV-C output, and reports relevant information to a mobile app. The parts for this workable prototype will be self-funded by members of the team. The idea of this project is to have an affordable UV-C air sterilizer, so our goal is to find inexpensive parts effective in sensing necessary metrics. The product we will be designing in the spring will be pricier as it includes an independent power source. The PV solar array and back-up battery supplying the power will be the largest expense. This brings us to the project timeline.

A project timeline is a visualization of project deliverables. It gives an overview of the tasks and milestones from start to finish, as well as providing a schedule to help disperse time and effort. Prior proper planning prevents mediocre performance. Therefore, creating a project timeline is so useful to keep the team on track to meet deadlines. Without visualization of all the tasks ahead, it becomes easy to fall behind.

The timeline highlights tasks the team needs to focus on to progress towards the end results of the final product. It represents information as a pictorial view of the time spent and tasks that are or will be completed. It includes all aspects of the project (research, design, acquiring supplies, progress checks and due dates, report, etc.) and the contributing member of the team. The team began this design project researching IAQ, airborne pathogens and the effectiveness of UV-C radiation on neutralizing VOCs and sterilizing microbes. Seeing that UV-C was a solution to unhealthy air, we started a design idea that would use air quality sensors to monitor indoor air quality and control the operation or a UV-C lamp.

Before building the equipment we tested a prototype. Before building the prototype we tested several sensors and their compatibility with a proper microcontroller that would allow us to connect to a smart device for the user to control the automation of the equipment. Our most critical path was to research these sensors and controllers, order and test them to make sure they work for the project. Once we found compatible sensors with the desirable metrics for our project, we will build a prototype for demonstration and testing. After finding desirable results with the compatible sensors in a working prototype we will design a module to house the equipment for easy installation in most practical applications as a deployable product. With this we will assess its marketability and make any changes before moving on to add the final features like solar power for off-the-grid use. Once that is complete, the team will have a final deployable prototype that would comply with our work breakdown.

The work breakdown structure shows the organization needed to complete all components of the project (research, design, acquiring supplies, working prototype, field testing, final report, etc.) in the time allotted. This includes a breakdown of tasks involved in the completion of the design on a component level. The project is divided into three essential parts: indoor features, outdoor features, and the mobile app feature. The three parts have sub tasks within each with varying levels of priority for the project timeline The chosen structure allows for simple and clear scheduling and task assignment. Details of what is required for each step of the project and the team member(s) assigned have been entered into a table and attached as APPENDIX G. On top of the work breakdown, we also needed to assess risks.

Risk assessment is a process to identify potential hazards and analyze what could happen if that situation occurs. The team was created a thourough chart organizing the normal to abnormal occurances our project may face and they time adjusment each would cause to the project itself.

The first step is to identify the hazards, then decide what might be affected and how. We evaluate the risks and decide on precautionary actions. Next, we record and implement the findings. It is important to remember that risk assessment is an ongoing process. As the project develops, the risks are likely to change and the team will continue to adjust with consideration to the latest information is it comes.

Every project has an unpredictable element of risk and every risk has a certain amount of probability and impact to our goal. Calculating the probability and impact of risk to a project helps us make an economic decision on whether to do it. Analyzing the risk provides useful insight into methods of mitigation to avoid probabilistic failure. We explain how the team will move to complete the project in the event of specific obstacles.

The risk assessment section of the report covers the predictable delays that specifically will target the project being designed. The assessment allows for a clear presentation of all levels of occurring issues from least likely to confirmable at each level of delay they would bring. The team brainstormed and found the various weaknesses the project holds, organized them, made game plans that would mitigate the delays they would bring and present the thoughts in the section.

The levels of delay occurrence were organized into 4 types represented by separation of percentages on the chart the team created. The lower row has the least likely of the events to occur, covering only the loss of our current information and report. Next row includes sensor burnout, as we have found out the IAQ sensors used have the potential to be overused and become useless. Also, we prepared for any damage that parts could experience upon delivery and general handling. Included as well is the chance team members become unavailable. In the present situation as the report and project is being made there exists the possibility of emergencies that keep team members from being able to contact the team such as natural disasters such as wildfires that are a reality.

The next row up covers the more likely occurrences of the mobile app code issues, COVID-19 related member delays, the IAQ, microcontroller, and app compatibility and communication issues. All with plans and back up resources waiting to cover their eventualities. Then come the more possible events: Incorrect parts that don't work with the design, social distancing due to the pandemic, general design failures including the housing of the components both inside and out, and finally the failure to meet the measurable metrics set by the unique design features. (See Table III 1 Features and Metrics[28]) Each has a plan and has been prepared for, even having time allocated for such events in the timeline. With everything figured out prior to the deployable prototype and accounted for, the team began focus on the prototype, making sure it worked well and properly utilized UV-C to do its intened purpose.

Germicdal UV has been used for decades to sanitize drinking water and surfaces. Its ablitiy to sterilize haradous pathogens has made it useful in disinfecting infectious areas of hospitals. Boston University School of Medicine has tested UV-C germicidal effects on SARS-CoV-2 and found it capable of eliminating more than 99.9% of Coronavirus in 5 seconds, which further confirmed that UV-C was the way for our product to be able to effectively sanitize the air ducts.

We used low-pressure mercury vapor lamps, which can efficiently produce near-monochromatic ultraviolet with most of its output at 253.7 nm. These UV lamps can be installed inside HVAC systems without intreference with the system's operation. Inside the system UV-C can sterilize the ducts and sanitize the air passing though it. UV-C by-product hydrogen peroxide can be distributed though the ductwork and building to disinfect contaminated surfaces. However, to verify that the device is working properly, we needed to collect data on it with our sensors, which we had tested to make sure that they are in proper working order and meet to the manufacturer's specifications.

To confirm germicidal UV operation and correct dosage, a UV sensor measured the UV output. We found the UV sensor to be fully accurate when compared to UV index reports from online weather websites.

The outdoor air quality index readings from the were found to be very inaccurate when compared to reports from online weather website. This sensor can reliably tell what the outdoor temperature, humidity, and air pressure is but not air quality index. The reason for this is that though this sensor can in theory give us a reading on air quality, it cannot detect particulate matter in the air, which is a crucial part of determining the air quality.

The indoor air quality sensor was used to tell how much CO2 and many TVOCs were in the air. To get the most accurate and up-to-date readings of the entire system, the sensor will be inserted in the duct along with the light to test the air moving through the HVAC system. Once all the sensors were found to be working properly, we ran tests to make sure the UV-C was doing what it needed to do.

The tests showed that UV-C reduced the measured TVOCs in the air, but prolonged use caused false readings. This false positive was caused by UV-C byproducts like hydrogen peroxide. We found this to be more likely in smaller, occupied spaces so it is especially important that the UV-C light is only operated as needed with air flow. Additionally, the UV-C device should not be oversized for the occupied space. Another sensor was tested and found to be more reliable indoor air quality sensor and was therefore used in place of the other one, though neither was perfect at differentiating between TVOCs and hydrogen peroxide.

Lastly the system power was needed to be tested. The bulb connected to the system needed to have its ability to stay on with the power system that was designed. The battery and solar panel specifications were tested, and a final set was found. The system was able to maintain power and light the UV-C bulb for the duration of 24 hours. The addition of a MPPT controller with Bluetooth access allowed for accurate readings of the battery, system and the panels as the 24 hours occurred.

Once all these tests were done and ready to go, all that was left was to test that the data being collected was being stored properly on the Google Sheets file and was able to be read by our mobile app. This process, primarily the setup, took a lot of time. However, after much hard work and deliberation, the app is too now up and ready for use. With the app up and ready to go, we can start focusing on marketability.

This market forecast is a projection of numbers, characteristics, and trends in our target market. It looks at market value, inspires reality checks, reviews the target audience, and helps visualize volume. We did research on our competition to find out their strengths, weaknesses, and position within the market, and tried to gauge where we would fit in, and who we would be likely to service. The industry overview shows the direction businesses are expected to develop the market.

We defined our target market and found research that showed a projection for a serious market expansion due to health concerns in the general public. Prices for comparable products and services are not readily available on a website because they are variable based on the individual consumer’s needs. Research of demographics showed a very specific target customer, which could limit our buyers, but make it easy to tailor our advertisements for best results. The location of our customers will likely be local early in our development. Defining the Psychographics of our potential customers was difficult to the untrained team members, however research showed consistencies in their situations provoke similar thinking patterns which we may appeal to.

II. SOCIETAL PROBLEM

According to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), “indoor air quality (IAQ) refers to the types and concentrations of contaminants in indoor air that are known or suspected to affect people’s comfort, well-being, health, learning outcomes and work performance [1].” Poor air quality is caused by particulate matter (PM) (e.g. pollen, dust, mold spores), volatile organic compounds (VOCs) (e.g. Formaldehyde, acetaldehyde, benzene, etc.), combustion by-products (e.g. Ozone, carbon-monoxide, carbon-dioxide, nitrogen-dioxide) and biological contaminants (e.g. viruses, bacteria, mold). Most of these pollutants are produced indoors. Different government agencies and professional organizations have set tolerable limits for air quality. [See APPENDIX I]

The purpose (HVAC) design for health care facilities is providing a safe environment for staff and vulnerable patients. The basic difference between air conditioning for healthcare facility and that of other building types stems from:

1. The need to restrict air movement in and between the various wards and departments (i.e. no cross ventilation).

2. The specific requirements for ventilation and filtration is to dilute and reduce contamination in the form of odor, airborne microorganisms and viruses, and hazardous chemical and radioactive substances. Ventilation effectiveness is very important to maintain appropriate indoor air quality.

3. The different temperature and humidity requirements for various areas and the accurate control of environmental conditions.

4. The design sophistication to minimize the risk of transmission of airborne pathogens and preserve a sterile, healing environment for patients and staff [2].

HVAC alterations and upgrades can be costly but proper maintenance and repair keeps HVAC systems running at peak performance, which directly translates to lower energy consumption and improved efficiency. As the HVAC system cools the air it collects the moisture. The condensed moisture collected in the dense coil fins can promote microbial growth dangerous to humans and inefficient to system operations.

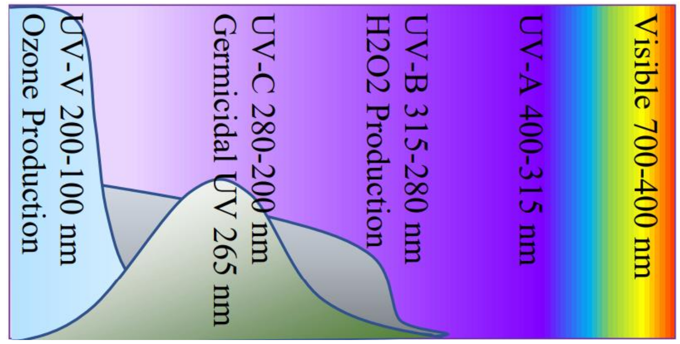

Figure II-1 UV light spectrum [3].

Due to indoor confinement and weatherproof construction indoor pollutants and contaminants are often more concentrated indoors than outside. Venting indoor air to the outside and bringing in fresh outdoor air can be costly if it needs to be conditioned to a comfortable level. An HVAC system can filter, dehumidify, cool and heat an occupied space to a comfortable level, but it cannot make fresh air and oxygen on its own.

UV light is intense electro-magnetic radiation between 100-400 nm wavelengths that can produce hydrogen peroxide from water vapor and oxygen in the air. At high energy wavelengths 180-220 nm UV can produce ozone which is toxic to microbes and humans. (see Figure I-2) According to the American Lung Association, “exposure to ozone causes a variety of adverse health effects, even at levels below the current standard.” [4]

According to ASHRAE the most effective UV-C wavelength against microbes is 265 nm and the recommended exposure is 50-100 milliwatts per square centimeter [5]. A low-pressure mercury vapor lamp emits ultraviolet-C light at 253.7 nm wavelength. The high energy radiation of UV-C damages the surface proteins of viruses, preventing them from infecting humans [6]. Any microbe that is not destroyed by initial exposure to UV-C or H2O2 survives with DNA damaged by photohydration, photosplitting, photodimerization, and photocross-linking preventing it from reproducing [7].

$$S = \frac{N_t}{N_o} = exp^{(-k\, I\, t)} \qquad \text{(II-1)}$$

I = 50-100 mW/cm^2

Equation II-1 exposure dosage of UV-C to microbes.

Here S is the surviving fraction of the microbe's initial population, N_t is the final number of microbe's after exposure time t[s], N_0 is the initial number microbe's, I [μW/cm^2] is the average germicidal irradiance the microbe's received, and k [cm^2/μW-s] is the specific rate constant of the microbe's change, which is determined experimentally and is changes with different microbes [8].

EEO defines the amount of energy (kWh/m3) required to decrease the concentration of a contaminant or a microorganism by one order of magnitude:

$$E_{EO} = \frac{A}{3.6 \times 10^6 \times V \times k_D \times C \times WF} \qquad \text{(II-2)}$$

Equation II-2 Equation for energy to decrease concentration of contaminant [4].

A is the irradiated surface area in cm2. V is the sample volume in liters. kD is the log10 fluence-based rate constant in cm^2/mJ. C is the wall plug efficiency given by the manufacturer (0.35 for LP UV, 0.15 for MP UV, and 0.004, 0.005, and 0.00444 for the 260 nm, 280 nm and 260-280 nm LEDs respectively). WF is the water factor, accounting for the UV absorbance and depth of the water. The factor 3.6 × 106 is to convert between hrs and sec, mW and kW, and L and m3.

One study suggests, "UV-C disinfection is a reliable alternative to chemical disinfection due to the increase of chemical-resistant microorganisms and the emission of harmful by-products after chemical treatment. Moreover, UVC disinfection does not generate toxins or volatile organic compounds and does not require storage of hazardous materials." [9]

UV-C light can breakdown chemical compounds and disinfect surfaces [9]. A study on UV-C disinfection showed that it could eliminate:

S. aureus,
P. aeruginosa,
E. coli,
B. subtilis
C. albicans
A. baumannii.

UV disinfection was not as effective as chemical treatment over short-term exposure, but with continuous exposure provided by HVAC equipment throughout the building microbial growth can be kept to a minimum. Another study showed UV-C light caused a significant reduction of microbes in the HVAC system correlating to a reduction in ventilator-associated pneumonia and the microbial load of neonatal intensive care unit (NICU) surfaces reduced to near zero [10].

In one study by Marianne Pavia, the effectiveness of UV-C on viruses, found a 44% reduction of viral infection in a pediatric long-term facility [11]. The study also suggested using UV-C with chemical disinfection was more effective and should not be a replacement for chemical and physical cleaning.

It has been well documented that HVAC systems are a popular haven for bacteria and fungi [12] [13] [14]. The biofilm that begins to accumulate on heat exchanger coils effect the heat transfer necessary for air conditioning. Inadequate heat transfer causes the system to operate at higher temperatures for longer time periods to effectively cool occupied spaces potentially damaging equipment and wasting electricity. An increase in energy efficiency of 10-15% is typical for cleaner coils. [15] UV-C disinfection on cooling coils can eliminate the growth of biofilm and accumulation of microbes affecting system performance.

Hospitals and health care facilities have to comply with ASHRAE (62.1) and other regulations standards that respect the humidity requirements, air change rates, and pressure.

There are many standards, codes, and guidelines on humidity, temperature, and airflow rates to maintain a health care space. According to Christopher J. Stip, codes that need to be demanded are "ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality", "ASHRAE Standard 170: Ventilation of Health Care Facilities", and "NFPA 90A: Standard for the Installation of Air-Conditioning and Ventilating Systems" [6].

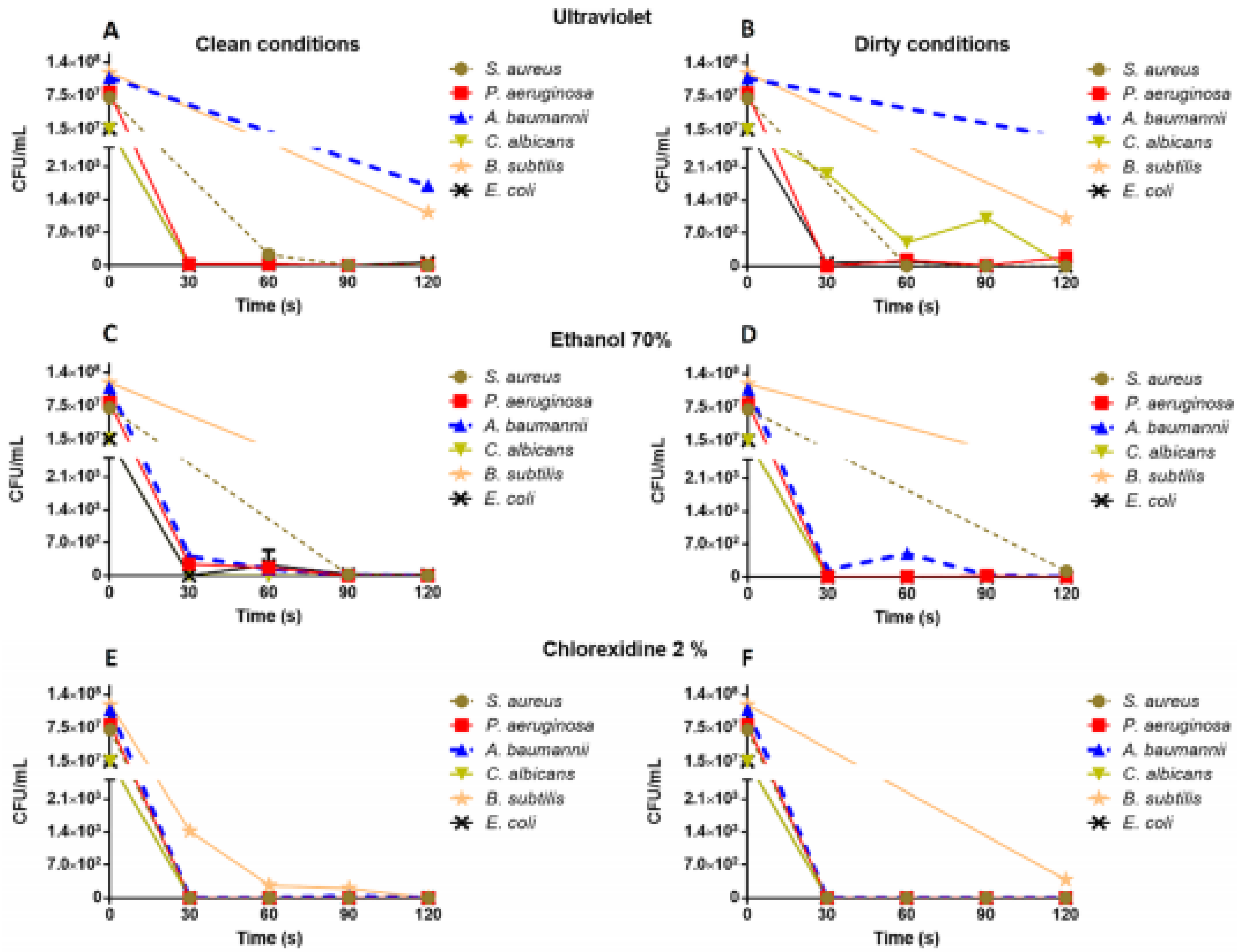

Figure II-2 UV-C disinfection in clean and dirty conditions at different exposure times [12]

For example, the NFPA 90A, "covers construction, installation, operation, and maintenance of air conditioning and ventilating systems, including filters, ducts, and related equipment, to protect life and property from fire, smoke, and gases resulting from fire or conditions having manifestations similar to fire." Many other codes/guidelines Christopher provides, from building to air quality codes [6].

However, though hospitals and health care facilities are safe, many other locations, such as small businesses, are not as safe as they do not follow the same standards of safety. COVID-19 is affecting both businesses and people alike because of this. For example, take a small local coffee shop. The coffee shop has a person owning it, whoever they might be, that wants to keep the coffee shop open, so they follow regulations and try their best to accommodate and evolve during these hectic times. On top of that, there are people employed there who need the money to pay their bills and people visiting the store who want their morning coffee. However, while their presence is crucial for the business to remain standing, with the increased risk of contracting COVID-19 in enclosed, public spaces, as well as increased regulation decreasing the appeal of going to such coffee shops, people must decide if visiting their local coffee shop is worthwhile and if they should just make coffee at home to avoid the unnecessary risks. This decision can prove too much for some people and sway them to the side of staying home, which greatly hurts the profits of many small businesses. For some, this massive cut in their monthly salary can prove to be too much and force them to shut their store down either temporarily or even permanently. According to Bartik et al. and their study of about 5800 small businesses, 43% of small businesses have closed temporarily and have claimed "reductions in demand" and "employee health concerns" as their primary reasons for closure [16].

According to the World Health Organization, (WHO), one of the ways that companies can prevent the spread of things like COVID-19 and influenza is to stop using indoor air conditioning systems on their recirculation modes [17]. Recirculation is when a system would take air from inside of a building and pump it back into the building after heating, cooling, and/or filtering it. This type of circulation is used when there are particulates and smells in the outside air that one would not want inside. For example, if one works in an office next to a farm, they will not want that outside air full of cow-related smells and methane mixing in with the air they breathe. Therefore, they would use the system on recirculation mode to reduce the amount of outside air getting in by as much as they could. The issue arises when the same person tries to use the recirculation mode while someone in the building has some viral infections, viruses, or bacteria. They could end up coughing or sneezing the virus into the air, where it would be taken in by the air conditioning system and pumped into other parts of the building. This is extremely dangerous, especially with the current COVID-19 pandemic, where people could end up getting COVID-19 from an air conditioning system and continuing their day-to-day activities thinking that because they were well over 6ft from anyone the whole day [18], that they are safe to be around others. These types of situations can be avoided if the air being recirculated is thoroughly cleaned of anything that could cause infection before it is dispersed into the rooms.

Boston University did a study on the Rapid and complete inactivation of SARS-CoV2 by -ultraviolet-C- irradiation. The study used a dosage of 849 microWatts/cm^2 on SARS-CoV 2 in wet droplets and dry particulate. The test samples had no detection of the virus after 9 seconds for wet droplets and no detection for dry particulate after 5 seconds [19].

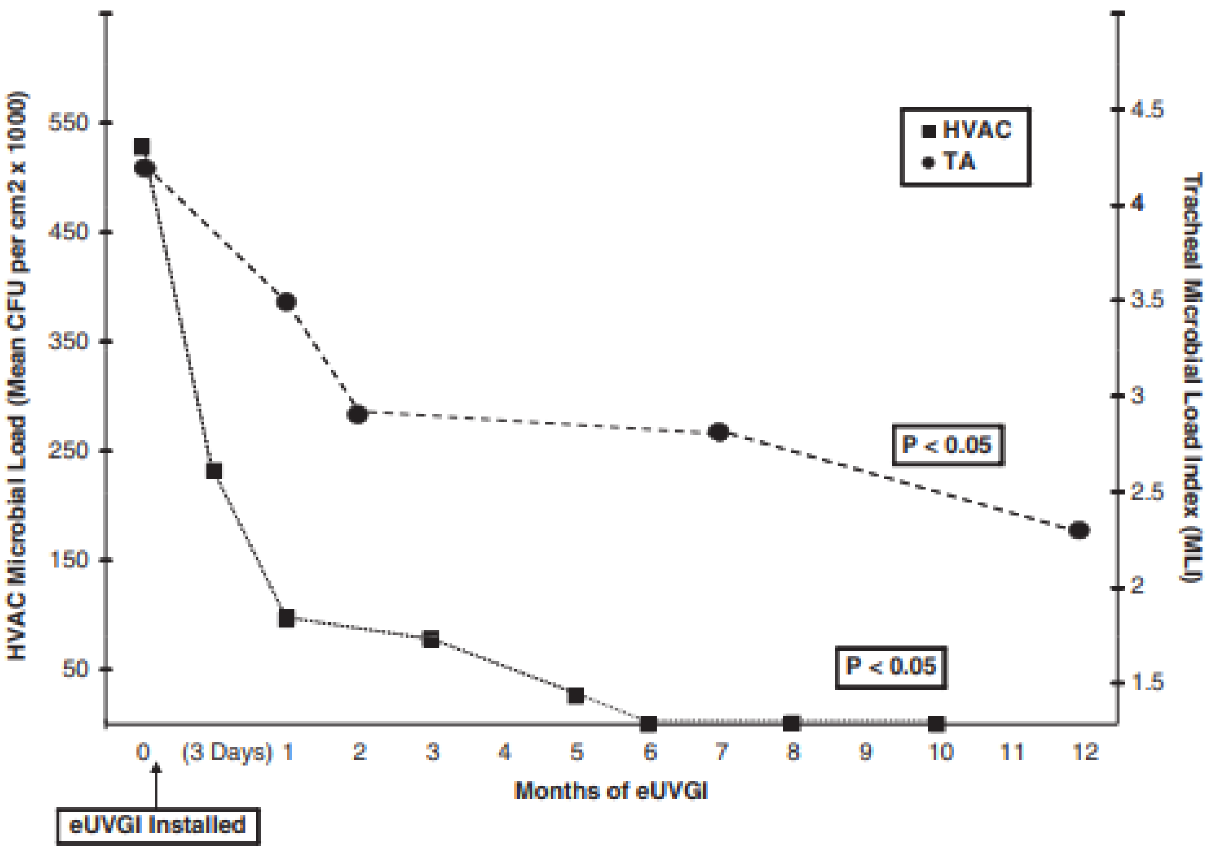

Figure II-3 Ultraviolet germicidal irradiation (UVGI) decreased the microbial load of the heating ventilation and air conditioning system (HVAC). [10]

Table II-2.
Airborne Bacteria and Virus Information

Bacteria	Description
Tuberculosis (TB)	"Tuberculosis (TB) is an infectious disease usually caused by Mycobacterium tuberculosis (MTB) bacteria. Tuberculosis generally affects the lungs but can also affect other parts of the body." [20] "Most people infected with the bacteria that cause tuberculosis don't have symptoms. When symptoms do occur, they usually include cough (sometimes blood-tinged), weight loss, night sweats, and fever." [21]
MRSA	"Methicillin-resistant Staphylococcus aureus refers to a group of Gram-positive bacteria that are genetically distinct from other strains of Staphylococcus aureus. MRSA is responsible for several difficult-to-treat infections in humans." [22] "MRSA is common in areas such as hospitals where there are many people with open wounds and invasive devices, such as catheters." [22] "After 72 hours, MRSA can take hold in human tissues and eventually become resistant to treatment. The initial presentation of MRSA is small red bumps that resemble pimples, spider bites, or boils; they may be accompanied by fever and, occasionally, rashes. Within a few days, the bumps become larger and more painful; they eventually open into deep, pus-filled boils. About 75 percent of CA-MRSA infections are localized to skin and soft tissue and usually can be treated effectively." [22]
Clostridium Difficile	"Clostridium difficile colitis results from disruption of normal healthy bacteria in the colon, often from antibiotics. C. difficile can also be transmitted from person to person by spores. It can cause severe damage to the colon and even be fatal. Symptoms include diarrhea, belly pain, and fever." [23]
Legionella	Legionella is a bacterium attributed to the pneumonia like illness called Legionnaires' disease. Symptoms which include shortness of breath, cough, fever, muscle pains, headaches, nausea, vomiting, and diarrhea often show up 2–10 days after exposure. Most outbreaks have been traced back to poorly maintained cooling towers and HVAC systems. The bacteria is prone to grow in warm water between 25°C (77°F) and 51°C (124 F) proper cleaning and regulating the water temperature to stay out of this zone prevents the outbreak of Legionnaires' disease [24].
Virus	**Description**
Norovirus	"Norovirus is a very contagious virus that causes vomiting and diarrhea. People of all ages can get infected and sick with norovirus. People with norovirus illness can shed billions of norovirus particles. And only a few virus particles can make other people sick." [25]
Coronavirus	Middle East respiratory syndrome coronavirus (MERS-CoV) and severe acute respiratory syndrome coronavirus (SARS-CoV). Have had large outbreaks in the past. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus is a new β-coronavirus, which first showed up in Wuhan, Hubei Province, China in the latter part of 2019 and its origin is still uncertain. SARS-CoV-2 is responsible for (COVID-19) disease. In February 2020, W.H.O. declared COVID-19, a "Public Health Emergency of International Concern" then in March, a pandemic. By analyzing clinical specimens' researcher have found the presence of SARS-CoV-2 RNA in various bodily fluids from infectious patients, showing that the virus infects more than the upper respiratory system and patient who recover can be reinfected [26].

Table II-1 Air borne Bacteria and virus information

III. DESIGN IDEA

This section will describe the design the group has decided would be fit to solve the problem stated in the previous section. The design concept that will be put forward is based on the research on the societal problem combined with technical skills we all have to be able to create the design. Our design idea uses UV radiation in the 200-280 nm band known as UV-C commonly used for disinfection and sterilization. The EPA defines a disinfectant as an antimicrobial that destroys or irreversibly inactivates infectious or other undesirable organisms, but not their spores. The EPA defines sterilizer as an antimicrobial that destroys or eliminates all forms of viruses, bacteria, fungi, and their spores.

Our research shows that UV-C radiation is effective at sterilizing microbial pathogens by damaging its DNA by photohydration, photo splitting, photodimerization, and photo cross-linking preventing it from infecting humans [7]. We also found that UV-C can chemically alter the air by breaking down VOCs and producing hydrogen peroxide from oxygen and water vapor in the air as a residual disinfectant. The UV-C module design aspires to use these features of UV-C to provide healthy, clean indoor air during the pandemic and allow for adaptability for the variety of HVAC systems and is based on cost consideration for health-conscious people with low income.

A. Project Proposal Overview

The UV-C module would consist mainly of 3 features. The main feature is a UV lighting fixture capable of being inserted into already installed HVAC systems with relative ease. Typically, HVAC components like evaporator coils have had many issues with promoting the growth of dangerous microorganisms. Because of the condensation moisture inside its tightly packed heat exchanger fins, the evaporator coil accumulates micro-organisms which live off the condensate water and fine particulates not captured by the filter. UV-C lamps have commonly been installed for system sterilization and efficiency, placing the lamp in the air flow after the air filter and before the evaporator coil. This is intended to irradiate the broad surface of the coil and sterilize microbes on the surface and in the air passing through it. For our application of germicidal disinfection of a room the ideal place for installation would be in the main duct after the furnace and other HVAC equipment. This is so that the residual hydrogen peroxide disinfectant is distributed directly to the occupied space disinfecting surfaces potentially contaminated by infected people. At both locations, the indoor occupants are not exposed to UV radiation and the installer has no need for entering the furnace compartment or air handler unit housing dangerous mechanical and electrical hazards of the HVAC system. This apparatus will be more cost effective than replacing an entire HVAC system. It will incorporate the same UV-C technology for air sanitation currently being used in sterilizing surfaces.

Next in the design are the sensors that will monitor the air, both inside and outside of the building. We have picked several multi functioning sensors that detect various air particulates and microbes to monitor the quality and sanitation of the air as it passes through the module. There will be two humidity sensors to deter the development of harmful mold in the system. Additionally, there will be an atmospheric pressure sensor and two Total Volatile Organic Compound (TVOC) sensors, which measure the air pollution levels. To monitor the air composition, we will include two carbon dioxide sensors along with a sensor to measure the air quality index. The sensors will send data to the main board and send that information to an app allowing for air monitoring and control of the module.

A third feature of the design is the solar component. The goal is to make the module energy independent for location versatility. A measured wattage solar panel will connect to a chargeable battery that has decent longevity and low cost. The battery will be connected to a DC down converter that can handle the power of the battery and send it to the main board to power all the features. Basic solar panels would be the best choice as this design is a constant balance of cost vs function to allow the UV-C module to be easily accessible by underfunded locations across the globe.

Our design addresses the problem by giving people an inexpensive way to clean the air going into their facilities, as well as giving them a way to monitor the air and control the system remotely via a mobile app. UV-C lamp can operate when user wants to control it with the app or by automation when the

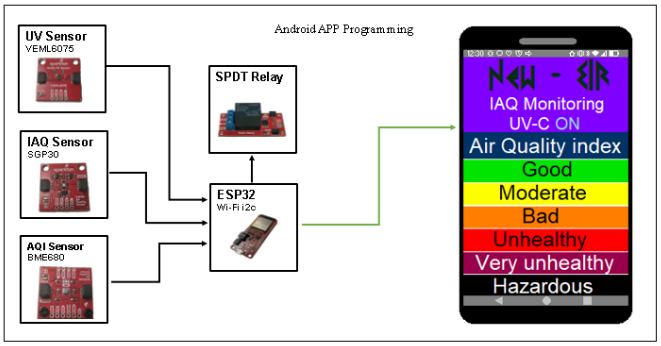

Figure III-1 Android Application [27]

indoor air quality sensor registers high levels of TVOCs causing unpleasant odors and toxic pollution in the air. The UV-C can neutralize VOCs from the incoming and interior circulating air. Using this approach, facilities will be able to cut costs in upgrading their ventilation systems, while keeping occupants safe from airborne pathogens. This method keeps energy costs low, which is an area of focus at healthcare facilities due to their high level of energy consumption and their extended hours of operation. The free mobile app that comes along with the product gives the user access to real-time data, should there be cause for concern in the building.

The module will use a combination of sensors, UV lights, Solar panels, a Battery charged by the panels, a DC down converter allowing power to be used from the battery for the sensors and lights. We plan to use the SparkFun ESP32 Thing Plus board to utilize the serialized input to read in the many sensors' signals [28].

The research done has led to the conclusion that even large, well-funded companies and buildings don't even choose to use UV-C as an option to increase air sanitation. It is a newer technology that can be implemented in a smart way to help now more than ever. The design is uniquely allowing for the increase in air quality at a lower cost than most air condition upgrades would cost as well as the versatility afforded by its power independence. It should be an extra measure to help battle harmful infectious diseases and lower preventable deaths around the globe.

There are different approaches on how to obtain air quality using different devices. Using Arduino, it is possible to build an air motoring system. By connecting to the internet, anyone can remotely see the air quality in any indoor building. In order to do this the next following items are needed: IoT boards with Wifi, gas sensors(MQ-2,3,7), Air Quality sensor (MQ-135), Android Device, Mobile application platform, IoT-cloud, jumper wires, and Arduino IDE.

Another way to approach air quality in using Raspberry Pi 3b+ (RPi). In a raspberry pi the first thing you have to do is download the software into your SD. In order to do this project a Raspberry Pi 3, SD card, SDS011 sensor (nova PM sensor), and a serial adapter is needed. The serial adapter is connected to the Raspberry Pi 3b+, while the SDS011 sensor is connected to the serial adapter. Using the RPi python, there are programs installed that must be unlocked in order to program the sensor. With the use of Arduino and Raspberry Pi there are programs in the device that make the job easier and faster. Apps and commands are built into these devices that make each senior work properly.

As we are pushing to use different sensors for our device that will be connected to an i2c, which will be collecting all our data. That data would later be displayed on the app. The i2c and building the app could lead to some difficulties but hoping to overcome them.

Some methods for UV germicidal disinfection are done by hand potentially exposing humans to UV light. Our device is installed inside the HVAC ductwork protecting humans from any exposure and allowing the HVAC equipment to distribute clean air and residual disinfectant throughout the vents and building.

Renovating an air conditioning system to sanitize the air as it circulates will cost thousands of dollars. This design creates an easy, affordable way to keep occupants breathing safely. Its portability allows it to be installed in most existing air conditioners, no need for professional installation. The ease of access to this unit means cleaning and maintenance are made easier, encouraging longevity. The solar panels combined with the battery keep energy consumption lower than other options. This feature furthers the cost benefit and makes the design ecological. All these aspects of efficiency and sustainability allow the product to be more easily available in areas that would otherwise not have access to similar clean air technology.

The UV-C module design will need some consultation with HVAC companies as well as the purchase of parts once a final design is established. We will need to consult with soldering technicians for ideas for the light fixture frame. The best resource we have is already in the group as we have some on hand HVAC work to default to. The design will need outside help especially when it comes to the frame. The project may also need some outside resources to help with learning i2c and its implementation in the module.

Repko, M. will develop an app that will enable the sensor system to be controlled. Repko, M. will calculate efficiency of power consumption and sanitization effectiveness, as well as help write code to interpret sensor data. Clements, G. will monitor and calibrate the UV power and sensor data intake. Garcia, A. will work on the connections between all components and features. The time to implement all the features of the module has been estimated to be between 80 to 200hrs.

B. Features and Measurable Metrics

The features of this design idea include air quality sensors one to measure outdoor air and one to measure the indoor air pollutants and contaminants (e.g., CO2, VOCs, Natural Gas). One microcontroller (with Wi-Fi/Bluetooth) to interpret data, automate the controls and connect to a mobile app. One UV-C lamp or more depending on the size of the heat exchanger to irradiate microbes in the air and on the surface of the heat exchanger. One UV sensor to measure the UV output. One humidity sensor to measure the relative humidity and notify the system if the humidity is too high possibly promoting mold growth. An exhaust vent to provide fresh outdoor air. A 24-Volt 20–30-Watt Solar PV array with 10-20 Amp-hour 24-volt battery to power the system independent of any electrical grid. A spectroscopy sensor will be included in the prototype to measure the effectiveness of the germicidal UV, it can also be included in the product to scan the heat exchanger to detect any organic matter accumulation on the surface.

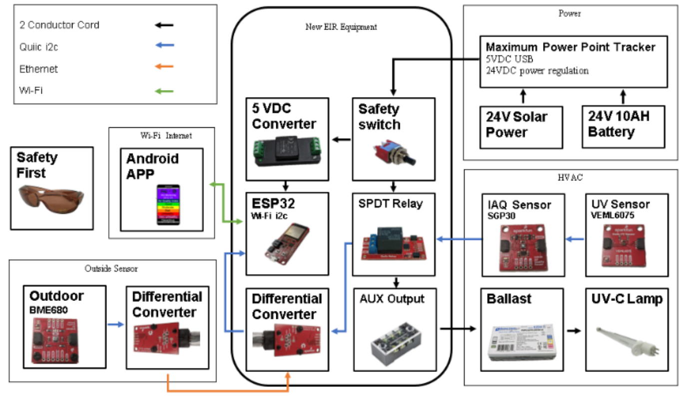

Figure III-2 Hardware Connection [29]

Table III-1
Feature and Metrics

Num units	Feature	Metrics
1	Indoor Air Temperature Sensor	20-25 °C
1	Humidity RH sensor	30-50 % RH
1	Air Pressure Sensor	101.325 kPa
2	CO_2 Sensor	1000-2000 ppm
2	Total Volatile Organic Compounds sensor	200-500 μg/m^3
1	Gas Resistivity sensor[1]	10-50 ppm
1	UV senser (200-370 nm)	50-100 mW/cm^2
1	UV-C lamp (254-265 nm)	13-26 W
1	PV Solar Array	24 V, 30 W
1	Back-up Battery	24 V, 20 AH
1	SPDT Relay	24 V, 5 A
1	32-bit microcontroller, with Wi-Fi	16MB mem., 520kB RAM
1	Mobile App	< 100 MB mem

Table III-1 Features and Metrics [28]

1 BME680 tested with 0.5-15ppm of VOCs.at 20°C and 50% RH for 220 hours 700mg/m^3 of Ethane, Isoprene /2-methyl-1,3 Butadiene, Ethanol, Acetone, Carbon Dioxide. [30]

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Table III-2
Specific Part and Measurable Data

Product Info	Metrics						
Sensor	UV-C 254nm (50-100mW/cm^2)	Temperature (indoor 20-25*C)	Humidity (RH 30-50%)	Pressure (101.325 kPa)	CO2 (1000-2000 ppm)	TVOC (200-500 µg/m^3)	Gas Resistivity (converted into AQI)
SparkFun UV Light Sensor Breakout - VEML6075 (Qwiic)	200–370 nm UV Resolution: 0.93 - 2.1 counts/µW/cm2						
SparkFun Air Quality Sensor - SGP30 (Qwiic)					400-60,000 ppm	0-60,000 ppb	
SparkFun Environmental Sensor Breakout - BME680 (Qwiic)[1]		-40- 85 °C	0-100%	30-110 kPa			0.05% - 0.11%
SparkFun Environmental Combo Breakout - CCS811/BME280 (Qwiic)		-40- 85 °C	0-100%	30-110 kPa	400-8,192 ppm	0-1,187 ppb	

Figure III-3 Specific parts with measurable data [28]

1 BME680 tested with 0.5-15ppm of VOCs.at 20°C and 50% RH for 220 hours 700mg/m^3 of Ethane, Isoprene /2-methyl-1,3 Butadiene, Ethanol, Acetone, Carbon Dioxide. [30]

IV. FUNDING

By the end of semester, the project will have a workable prototype that monitors air quality, operates a UV-C lamp, measures the UV-C output and reports relevant information to a mobile app. The parts for this workable prototype will be self-funded by members of the team. The idea of this project is to have an affordable germicidal UV-C air sterilizer, so our goal is to find inexpensive parts effective in sensing necessary metrics. The end product will be pricier as it includes an independent power source. The PV solar array and back-up battery supplying the power will be the largest expense. For preliminary sensor testing Clements, G. will order several sensors within a total price range of $200-300 and test their metrics and compatibility. With proper sensors selected Torres, R. will use his funds to order parts for the prototype to be assembled and passed on to Garcia, A. (See Table IV-1 Specific parts with price .) Then the prototype will be tested by Costello, A. and a solar panel with a reasonable price range will be added for operating independent of a power grid. With this equipment we should be able to take UV-C used in big hospitals and find an inexpensive solution for small businesses to have clean, healthy air.

Table IV-1
Specific Parts and Prices

Product Info		Price (USD)		
Parts	URL	Testing	Prototype	End product
SparkFun UV Light Sensor Breakout - VEML6075 (Qwiic)	https://www.sparkfu	6.95	6.95	6.95
SparkFun Air Quality Sensor - SGP30 (Qwiic)	https://www.sparkfu	19.95	19.95	19.95
SparkFun Environmental Sensor Breakout - BME680 (Qwii	https://www.sparkfu	18.95	18.95	18.95
SparkFun Environmental Combo Breakout - CCS811/BME2	https://www.sparkfu	35.95		
SparkFun Triad Spectroscopy Sensor - AS7265x (Qwiic)	https://www.sparkfu	64.95		
SparkFun Thing Plus - ESP32 WROOM	https://www.sparkfu	20.95	20.95	20.95
SparkFun Qwiic Cable Kit	https://www.sparkfu	7.95	7.95	7.95
SparkFun Qwiic Single Relay	https://www.sparkfu	11.95	11.95	11.95
SparkFun Breadboard Power Supply Stick - 5V/3.3V	https://www.sparkfu	0	11.95	11.95
JST Jumper 2 Wire Assembly	https://www.sparkfu	0.95	0.95	0.95
Terminal Block - 3 Position (15A, 600V)	https://www.sparkfu	0	1.95	1.95
PSM1GPH18DW24 Robertson UV Germicidal Ballast	https://ballastshop.	0	29.95	
10-1201A Atlantic UV Surelite 12Vdc MiniPure Ballast	https://ballastshop.	0		134.95
24V 253.7nm UV-C bulb 20W 4-pin	https://www.1000bul	0	11.3	11.3
24v Battery 10 Amp-Hours	https://www.1000bul	26.31	0	52.62
24V 50W Solar panel	https://www.google.c	0	0	74.83
MPPT Solar Power Management Controller	https://www.amazon	0	0	89.99
Total		$ 214.86	$ 142.80	$ 300.42

Table IV-1 Specific parts with price [28].

V. PROJECT MILESTONES

After we formed a team at the beginning of class, we had until September 28 to define a large impact, long duration societal problem, then researched the various aspects of it. We decided on the recent pandemic and the problem of indoor air quality for people confined to indoors during the lockdowns and the healthy problems regarding pollution, and airborne diseases transmitted by circulating mixed air.

To come up with a design solution, we researched methods used in hospitals for sterilization of surfaces and circulated air. We found that germicidal UV-C is widely used in hospital wards for infectious diseases to reduce the spread of airborne disease to other patients and staff. We also found that UV-C irradiation neutralizes VOCs and kills microbial growth on HVAC evaporator coils that would reduce the efficiency of heat transfer of the refrigerant. By September 28 we decided on a solution using a compact UV-C module to install in already existing HVAC systems that would monitor the air quality and sterilize airborne diseases using germicidal UV-C.

This is our most critical path to reach our next step of building a prototype we needed to research, order and test parts by October 25 to have time to build the prototype. We researched the aspects of our proposed solution, like the cost, materials needed, as well as estimate how effective it would be at clearing the air of particulate matter, pollutants, and airborne diseases. We found sensors for detecting TVOCs, CO2 and other environmental parameters (i.e. temperature, relative humidity, etc.). We made a chart of desirable features and measurable metrics to incorporate into the project. (See Table III-1 Features and Metrics) We selected several compatible sensors that would work together and connect to a microcontroller. The preferred microcontroller would have built-in Wi-Fi to connect to a smart device for a user interface and more than 5 megabytes storage space for the programming and sensor data. A critical task for this step was ordering parts early to make sure we had time to get the right parts, test sensors and reorder any before we moved on to building a prototype. We tested each feature’s effectiveness to make sure it was sufficient for its desired metric.

Once the research and testing are completed, we will have developed a prototype of our proposed solution by December 11. We will test the prototype against desirable metrics and research its marketability to businesses affected by the pandemic lockdown and other applications for IAQ. If it needs any improvements, we have till March to redesign any simple aspects for building the final deliverable prototype.

After we test the working prototype and assess its marketability in the spring, we can redefine our problem statement and redesign any issues before adding more features for the final deployable prototype. After further testing, we will need to go back and see what worked and did not work. Then add better features like solar power for off grid applications in developing countries and international language translations for the user app. The final deployable prototype will be a single module easy to install in most common applications with a small remote module for an outdoor air sensor. This will be ready for demonstration by March 30.

VI. WORK BREAKDOWN STRUCTURE

The project is divided into its three essential parts: indoor, outdoor and the mobile app feature. The three parts have sub tasks within each with varying levels of priority for the project timeline.

The first components that were purchased by the team were the sensors. The three sensors to be used with the design were chosen and purchased in mid-September: The SGP30 IAQ sensor for inside the HVAC system, the SI1145 UV-C sensor, and the BME680 outdoor IAQ sensor. These sensors use i2c communication for streamlined performance and this key feature played into the design.

The two main features that drive the project design are the UV-C bulb and the Board. These components were key in making decisions on the design. Both items are chosen early on in October to allow for the rest of the design to fall back on details needed to run them. The bulb power level will determine the need for type bulbs and determine the settings for the UV-C sensor. The ballast needed to power the bulb is chosen along with it.

The Board chosen, also in October, allows for final decisions on the communication of the app and the sensors. The board chosen to use is the SparkFun ESP32 Things Plus board. It allows for the i2c communication with all the sensors and built-in Wi-Fi for easy integration with the mobile app. Team members Clements, G. and Garcia, A. spent two weeks of research to come to the design decisions.

Late September was the time the app was begun by team member Repko, M. This team member has the most in-depth background in software and programming language and took it upon himself to begin research and development of the mobile app for the project. The app has a time frame for December for a usable product and a May deadline for the polished final design. The December deadline includes a display for all the sensor data, user activated power switch for the bulb and an adjustable setting for automatic activation of the UV-C bulb. The app will allow notifications to update on levels outside and when the levels inside match the setting level. The December deadline will have all necessary information to allow for international use: language change and temperature reading change.

The app will need the information from the sensors to function properly, so the next step is the accumulation and communication of the data to the app. The i2c communication has been researched since late September and Costello, A. and Garcia, A. both along with Repko, M. have dived into having a functioning system by the end of December. The main hub of communication from the sensors to the board using i2c will be sent through a Single Pull Double Throw (SPDT) relay. The component will be picked late October so that the information can begin to be organized and i2c can be tested.

The final part of the project involves powering both the indoor and outdoor groups. The type of solar panel to be used is set to be chosen in late November and not needed to be implemented until February of next year as it has little effect on a working prototype. The battery with specific specs has been selected and will be purchased mid-November once the full system is tested on a steady power grid. The battery having higher voltage than needed has the design needing a DC power converter to bring down the high voltage to 5 V for the board.

The battery will need to power the bulb and the board and safety features are needed for this design. That step involves a safety switch that will cut power to the UV-C lamp if the equipment is not installed properly or if it is tampered with possibly exposing technicians or users to UV radiation. Also, a resettable fuse for overcurrent protection. This component is a needed safety measure that Clements, G. has found to prevent the battery from being shorted out and will implement in late November once the battery is assembled into the prototype. Most of the wiring together of the components to the battery and the final assembly is scheduled for early December. The working prototype has an early December schedule with hopes it is finished sooner, allowing for the speed up addition of the solar panels. The wiring and configuration of the features together is being tasked to Torres, R. and all the members who have worked on each part. Each component also needs a housing and fixture, and the wires need to be protected. As the prototype is built, designs for the fixture and housing are put together and created for each part of the design. The outdoor frame that will hold the panel, battery and board will be prepared by mid-November. i2c for these components are designed for short distances and will need to be modified for the outdoor sensor if the wire connection is longer than 1 meter. The wiring protection is not vital to the prototype and will be taken care of later in February and March. Each task and feature have more than one member to back up the main assigned team member. Repko, M. has the mobile app as his main task. Clements, G. has the components selection and testing. Garcia, A. will cover the i2c and the board, sensor housing and battery. Costello A. has control over the lighting fixture and relay data configuration. Torres, R. has the combination of all the features and the frame and housing of the outdoor feature. The prototype is set to be ready in December.

VII. RISK ASSESSMENT

Projects will be met with problems of all sizes and degrees. The recent Coronavirus pandemic provided the inspiration for this project, but it also provides some problems to avoid while developing and engineering it as a team. Social distancing as required by the University and state, has added to the complexity of problems. The way to dampen, if not outright negate, the impact of these problems on the project is to make sure that the team members are communicating. The open dialogue perpetuated by the team leader is what allows the team to be prepared for these eventualities. The low probability issues such as team member burnout and/or unavailability, damaged parts, sensor burnout, and even team member displacement caused by natural disasters can all be accounted for, and their impacts negated through consistent team meetings. At these meetings, plans are put in place and the issues are prepared for because the team members understand the impact these issues might have. These types of issues are not code red, so to speak, but must still be accounted for in the off chance they do occur. However, the more likely scenarios, such as errors in the code, compatibility issues, power miscalculations, and the looming risk of COVID-19 need a more robust contingency plan and time set aside within the timeline of the project in order to fully flesh out the possible causes of these problems and how to avoid or deal with them. The issues that are high probability are a constant battle to mitigate because they are unpredictable and yet are very likely to happen one or more times or be a recurring theme of sorts. These issues include social distancing requirements, wrong parts being received, design flaws found in the project when the project is in the design and prototype stages, and the measurable metrics not being met. These issues can cause serious delay in progress, if not outright stop it, and each team captain, for their allotted time slot, must prioritize which ones to keep an eye on and must also have a plan of attack in case the issue does arise.

The low probability risks are made into low impact risks through team member communication, and there are many examples of these types of risks and how to mitigate them. Examples of these risks are team member burnout, team member unavailability, sensor burnout, and the fact that the team does not have access to many of the physical on-campus resources we normally would have because of COVID-19. The first low probability risk is team member burnout. Team member burnout is when a team member feels overwhelmed with either in-class or out of class issues. Many people have been in isolation for months and mental health can deteriorate when these conditions are combined with stress. Any member being overwhelmed is not only dangerous for that member, but also for all the other members as a struggling and possibly under-performing team member can hold back work and in the worst of cases, crush the team's morale. To combat this, the leader constantly checks in with the team and keeps an open dialogue so that anyone under too much pressure can share what kind of pressure they are feeling, what impact the other classes are having on them, and the member's emotional stability each meeting. The team does its best work when they know that the other members are ok and are more willing to pick up slack when a member is upfront and honest. The meetings also take inventory on how the members are feeling, the things delaying their work, and the team's plans to combat these delays. There is a lot of uncertainty to designing a new product, so we had to start with testing a prototype. Before designing the prototype, we had to order and test several sensors and controls to limit the uncertainty of their effectiveness and determine their limitations.

Another issue that can occur is burnout of these sensors. If a sensor burns out, we have contingency plans in the form of back up sensors and the funds to order new sensors if the need arises. Torres, R. is assigned to revisit part purchasing sites to keep the group up to date one any availability changes. This way, if a part is unavailable on one website, Torres, R. will know where to look or who to contact about getting a replacement. Additionally, there is a team brainstormed response to sensor issues and general damaged part delays. The response consists of testing the part separate from the rest of the components, troubleshooting using the seller's web guide, contacting customer support, and having the reserve funds and time to order new parts. Additionally, if a team member becomes unavailable with no simple way to check on him, we have prepared as many ways as we could to think of to reach them. These ways include texting and/or calling them, contacting them via email, and reaching out to the professor to see if they had received any notice from the student. If these do not work, we plan to cover for the team member as best as we can as personal emergencies are rare but possible when working over the course of such a hectic year. Lastly, there is the ever-looming problem of not having access to the on-campus resources like lab computers. Our response for this is to simply work at home and communicate via Microsoft Teams and text messages to make sure we are all on track.

The more common issues have a more robust plan when it comes to mitigating their occurrence. The main common issues come down to code problems for the mobile app, compatibility of the sensors and components, and miscalculations with power for the entire system. It is easy to become stuck on a problem, or function when coding and a person can sometimes take days to find a solution. A fresh set of eyes can be very helpful, and we have confirmed availability via Zoom meetings with willing helpers to screen share and troubleshoot code. These are likely to occur because there are many sensors included in the whole device and each team leader is aware and prepared in case these issues happen. Repko, M. has back up plans and outside sources to help with any code issues that occur. Clements, G. and Torres, R. also have sources to help with component communication issues and have contacts with the sellers for any deeper issues and questions.

As proof these issues are indeed common, we have already run into issues with the power calculations. The power miscalculations have already occurred involving the solar panel power rating and to resolve this, the team worked together to find a proper replacement panel. This was entirely possible because as a team, we were aware that this issue could very well happen and have accounted for this by purchasing parts well before we are able to get to using them. Having the solar panel purchased early was crucial to getting this resolved quickly. Torres, R. has been in contact with customer service on the panel company to change and request updated parts that fit the specs. Though all the common risks are detrimental in their own way, the most worrisome of the common risks is the COVID-19 pandemic. Members are doing their best to avoid unnecessary outings and contact with those that may have come into contact. Basic CDC guidelines are followed but a plan is still in place in the off-chance that one of the team members does in fact contract COVID-19. Any member affected directly will inform the team immediately and, if the member is feeling unwell because of COVID-19, all his work will be divided among the rest of the team to try and guarantee no loss of progress and allow the affected member to focus on recovering, so that they can be healthy and safe. We also have taken into consideration if relatives of members contracted the disease as well and in the case of this, we will follow the same communication tactics we would use for member burnout protocols in order to allow the team member to focus on helping them in what way they can, if the need arises.

The final and most significant risks of the project are impactful enough to really hurt the project and therefore need to be a constant focus for the team. These risks have been discussed very frequently and exist at the back of the team member's minds when a task is planned. In fact, some of these risks have already begun affecting productivity and planning from the start of the class. One of these significant risks is social distancing. Social distancing as required by the university and state, is at this point a fact with this project and has found to only hurt progress later into the year. However, even at the start, more time went into planning and discussions to make sure that we future-proof our plan regarding social distancing. We have used the diversity of the resources the internet offers to allow us to remain in close contact and be able to share documents and reports online. The physical aspects of the design (i.e., hardware assembly and testing) has been assigned in steps to start with Clements, G. ordering basic components for preliminary trials and will still have parts for any further test and troubleshooting. Torres, R. will order and mount the components. After that, Garcia, A. will design and build the housing and pass it on to Costello, A. for further testing. While Repko, M. shares the software he has developed for the app. The problem of receiving a wrong part has already occurred. Members that have purchased parts have all the contact information for the sellers on hand and quickly have tackled replacing the parts that were incorrectly sent and it was reflected as such in the timeline. Another significant risk is the ever-evolving design of the product. The design will almost definitely change from its original concept as the parts and wiring come together for testing. Trying to wire into a 120 Volts AC HVAC system would be too risky for us. We have avoided that risk with supplying our own 24 volts DC supply using Solar panels. Even though we are working with a 24 VDC, it might be safer for a human, but we can still have short outs, or the circuit can get damaged. We have designed it with a fuse and proper wiring gauge. Our research shows that UV-C is effective at improving indoor air quality and sterilizing microbes. Our preliminary tests using sensors and controls have shown that our design idea is possible. This allows us to progress towards building a prototype. Early designs are rarely kept for the finished product and the team is aware of this and has accordingly kept that at the back of their minds. Further testing will determine these issues, along with any changes to the measurable metrics that we will need to make. (See Table III-1 Features and Metrics) The features for the design may need to be updated or changed as we discover possible impossibilities in terms of design. These kinds of risks are almost treated as fact when discussed in team meetings and everything is planned with the idea that they will happen and what effects it has later in the project.

Table VII-1
Risk Matrix

Probability (Not likely to Near Certainty)	5 Near Certainty	0.9	1.8 Social Distancing Wrong part	2.7	3.6 Design flaws Metrics not achievable	4.5
	4 More Likely	0.7	1.4	2.1 Power miscalculation	2.8	3.5
	3 Likely	0.5	1.0 Team member burnout	1.5 COVID19	2.0 Coding Issues Compatibility	2.5
	2 Less Likely	0.3	0.6	0.9 Part damaged Sensor Burnout	1.2 Team member unavailable	1.5 Natural Disaster
	1 Not Likely	0.1	0.2	0.3	0.4	0.5 Data loss
	0	1 Minimal	2 Tolerable	3 Limited	4 Compromising	5 Jeopardizing
		Impact (Minimal to Jeopardizing)				

Table VII-1 Risk Matrix (Risks identified by probability and impact) [27]

VIII. DESIGN PHILOSOPHY

The focus of our design project was insuring safe and healthy indoor air that would be cost effective and easy to integrate into any air handling system. CO2 and VOCs have always been a concern but the noval coronavius pandemic has made circulated indoor air more hazardous. Our team resurched ways hospitals have metigated the spread our infectous diseases using UV lighting.

Boston University School of Medicine has tested UV-C germicidal effects on SARS-CoV-2 and found it capable of eliminating more than 99.9% of Coronavirus in 5 seconds in a dry environment with 849 µWatts/cm^2. (See Figure VIII-1 Boston University School of Medicine UV-C test .That is a total dosage of 4,245 µJoules/cm^2 [19].

Without the phosfluorescent coating, low-pressure Mercury vapor lamps are not fluorescent tubes. A low-pressure mercury vapor lamp produces little heat and is nearly monochromatic with most of its output at 253.7 nm with other small spikes in wavelengths dispersed throughout the UV and violet light spectrum [8]. Some UV devices waste electricity by running constantly, we believe the UV lamp only needs to be on as needed to sterilize the air and neutralize VOCs and when the circultion fan is running. This would mean multiple start-ups which can limit the lifespan of the lamp.

The negative resistance of a floursent lamp means as the lamp starts up an increase in current will cause a drop in voltage. The drop in voltage will cause a positive feedback lowering the resistance and increasing the current. To propery control the current flow of the UV lamp we needed a separate electrical device called a ballast which is connected to the circuit to ignite the lamp and regulat the current. We used an electronic ballast programmed to preheat the lamp electrodes before igniting the UV lamp. The preheating increases the resistance in the lamp allow it to have less amp draw on start-up and better

Seconds	0.8	2	3	4	5	6	9	120
Wet virus	517	170	53	13	13	2	ND	NT
Wet virus control	2150	2100	2167	2267	1450	1700	1550	NT
Percent reduction	75.9	91.9	97.6	99.4	99.1	99.9	>99.9	N/A
Dry virus	85	39	8	1	ND	ND	ND	ND
Dry virus control	513	523	503	563	613	550	563	420
Percent reduction	83.4	92.5	98.4	99.8	>99.9	>99.9	>99.9	>99.9

Figure VIII-1 Boston University School of Medicine UV-C test [19].

lifespan. To make the product safer for home owners and installation technicians we decided on a ballast that would operate on low voltage 24 VDC instead of normal resisdential 120 VAC. 24 VDC would make it safer to connect power to the device using a wall plugin adapter designed for 60 Hz in North America or 50 Hz AC for other contries. It also allows for dirrect connection to 24 VDC PV solar panel.

With the device connected to a solar panel and backup battery we deciseded to also use a Maximum Power Point Tracker (MPPT) to regulate power going to the device and current going to charge the batteries.

We decieded on ESP32 Thing Plus WROOM as the microcontroller to turn the lamp on as needed. The ESP32 has an I2C bus to easily connect to a SPDT relay to operate the UV-C lamp and ballast. The ESP32 uses WiFi to connect to smartdevices allowing the user to turn the UV-C lamp on or set the system to automaticly turn the UV-C lamp on if the TVOCs were above a curtain level (See Figure III-1 Android Application). The ESP32 also connects to sensors to monitor the level of UV output, CO2 and TVOCs in the air.

Testing the air qualtiy sensors showed that they were able to detect CO2, TVOCs and UV by-products (i.e. Hydrogen Peroxide) allowing the devise to automaticly to turn on the UV when TVOCs are too high and turn off the UV when by-products accumulate too much.

The remote outdoor air quality sensor proved to be less reliable to determine the outdoor air quality by the standard index used so we will have to us our own index.

AQ Index	Air Quality
0 - 50	**Good**
51 - 100	**Moderate**
101 – 150	**Bad**
151 – 200	**Unhealthy**
201 – 300	**Very Unhealthy**
301 – 500	**Hazardous**

Air Quality Index number and color code [30]

IX. DEPLOYABLE PROTOTYPE STATUS

Without the phosfluorescent coating, low-pressure Mercury vapor lamps are not fluorescent tubes. A low-pressure mercury vapor lamp produces little heat and is nearly monochromatic with most of its output at 253.7 nm with other small spikes in wavelengths dispersed throughout the UV and violet light spectrum [8].The UV lamp can be tested for UV-C output with a photochromic fluorescent indicator with analytic sensitivity to 254nm (See Figure IX-1 Low-pressure Mercury Vapor UV-C lamp Indicator).

The UV producing gas is contained by a fused quartz sleeve that allows for 90% transmittance of UV at 253.7 nm giving our UV-C lamps 30-33% Germicidal Output efficiency. The correct exposure of Germicidal UV on a surface at a distance of 1 meter is determined by the Germicidal UV output divided by the surface area of the radiation pattern. Using the geometric shape of a cylinder 34.45 cm long (See Table D-1 UV Dosage [30]) for the surface area of the radiation pattern, a 17 Watt UV-C lamp will irradiate the surface area one meter away with 61.558 µWatts/cm^2 (See Equation IX-3) every second. The intensity of UV radiation increases by the inverse square of its distance from the UV light source, so at a tenth the distance the intensity will be 100 times greater, or in our example 6,155.8 µWatts/cm^2, effectively eliminating 99.9% coronavirus in less than one second. For reference, the typical UV-A exposure of sunlight at 36° azimuth is 4,300 µWatts/cm^2; however, the Boston University study found that "UV-A was a poor means of inactivating SARS-CoV-2" in comparison to inactivation by UV-C [19].

$$Airflow = \sqrt{Pa} \times 4642 \left(\frac{m}{\text{sec}}\right) \quad \text{(IX–1)}$$

Equation IX-1 Airflow

$$Cylindrical\ Area\ = r2 + r2 + \ 2rl\ (cm^2) \quad \text{(IX–2)}$$

Equation IX-2 Cylindrical Area

$$Exposure = \frac{GUV\ Output}{Cylindrical\ Area}\left(\frac{\mu W}{cm^2}\right) \quad \text{(IX–3)}$$

Equation IX-3 Exposure

Where *r* is the radial distance from the UV light source and *l* is the length of the UV light source.

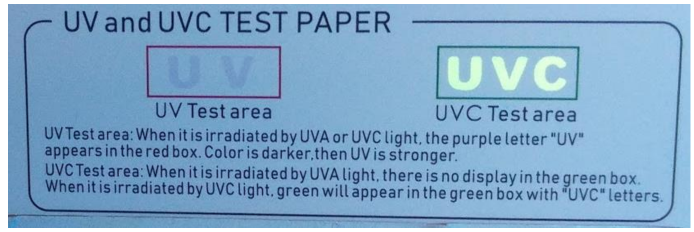

Figure IX-1 Low-pressure Mercury Vapor UV-C lamp Indicator [27]

To test the effects of the device on the flow of air inside HVAC ductwork the static air pressure was measured upstream and downstream of the device before and after installation. The measurements showed a very minimal change. The upstream changed a difference of 0.00249 kPa and the downstream changed a difference of 0.00497 kPa for reference the normal air pressure was 97.70 kPa (See Table IX-1 Air flow test for New-EIR installed in duct). With low turbulent interference of the device installed the air flow will be laminar, making it easier to determine the UV dosage. (See Figure IX-2 Laminar Flow Germicidal UV Dosage

Determining the dosage for particulate in air flowing past the UV-C lamp inserted into an HVAC air duct will need to include the effect of the laminar flow of the air through the air duct. The exposure time for the faster moving air in the center of the duct will be less than the slower moving air near the sides of the duct. However, it is this slower moving air that is also receiving the least intense UV-C. Given the complexity of calculating the efficiency, geometry, inverse square law, and laminar flow in the air duct, it is simpler to calculate the maximum and minimum time for proper dosage.

Particulate matter traveling a distance of 2 meters (6.56 ft.) through a 0.4064 m (16 in.) diameter duct past a 17 Watt UV-C lamp would encounter 503.562 µWatts/cm^2 of germicidal UV-C radiation at the edge (See Equation IX-4), requiring the

New-EIR installation effects on Static Air Pressure (normal air pressure 97.70 kPa)				
	Upstream		Downstream	
	Before	After	Before	After
Max	0.09207	0.08958	0.08212	0.07216
Min	0.06221	0.06718	0.04728	0.04976
Ave	0.07963	0.07714	0.06967	0.06470
Diff	0.00249		0.00497	

Table IX-1 Air flow test for New-EIR installed in duct [27]

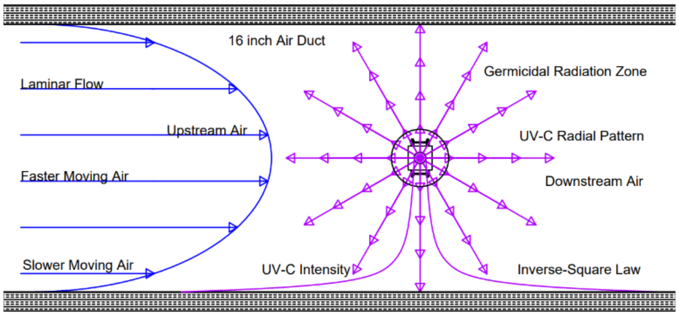

Figure IX-2 Laminar Flow Germicidal UV Dosage [27]

particulate to experience 1.32 seconds of exposure in order to inactivate the same minimal amount of 83.4% as in the Boston University Medical Resurch on SARS-CoV-2 exposure to UV-C [19]. While the air near the center can reach an exposure intensity of 10,198.476 µWatts/cm^2 (See Equation IX-5). This will allow the air to pass through the radiation zone with an exposure time of 0.416 second and still receive enough irradiation to inactivate 99.9% of SARS-CoV-2 (See Figure IX-2 Laminar Flow Germicidal UV Dosage). If the 16 inch duct has a CFM of 550 cubic feet per minute, most of the air will travel the 2 meters of the radiation zone in 1 second.

$$Edge\ Exposure = 2\int_{0.2032}^{1.2032} \frac{61.558}{x^2}\,dx \left(\frac{\mu W}{cm^2}\right) \qquad \text{(IX–4)}$$

Equation IX-4 Edge Exposure

$$Center\ Exposure = 2\int_{0.006}^{1.006} \frac{61.558}{x^2}\,dx \left(\frac{\mu W}{cm^2}\right) \qquad \text{(IX–5)}$$

Equation IX-5 Center Exposure

$$Total\ Dosage = Exposure \times Time \left(\frac{Joules}{cm^2}\right) \qquad \text{(IX–6)}$$

Equation IX-6 Total Dosage

$$Exposure\ Time\ = Joules\ /\ Watts\ (sec) \qquad \text{(IX–7)}$$

Equation IX-7 Exposure Time

The narrow round shape of the UV lamp will allow for the device to be placed into ductwork without altering the air flow. Our device can be installed in two different locations in the HVAC system. The first location would be placing the lamp after the air filter and before the evaporator coil to sterilize microbes on the surface of the coil and in the air passing through. The pros of this location include irradiating the broad surface of the coil and eliminating biological growth in between the coil fin to prevent fouling.

SARS-CoV2 Exposure to 849 µWatts/cm^2					
Seconds	0.8	2	3	4	5
Dry CoV	85	39	8	1	0
Control	513	523	503	563	613
% Reduce	83.4	92.5	98.4	99.8	>99.9
Dose µJ/cm^2	679.2	1,698	2.547	3,396	4,245

Table IX-2 Boston U. Med research [19]

The second location for installation is in the duct, but only if there are at least 2 meters (6.57 feet) of straight ductwork leaving the furnace or air handler unit. This is so the residual hydrogen peroxide disinfectant is distributed directly to the occupied space, sanitizing surfaces without exposing humans to UV radiation.

To confirm germicidal UV operation and correct dosage, a UV sensor (VEML6075 by Vishay Semiconductors) will measure the UV output calibrated to the UV-C for the placement distance of the sensor [31]. To assure owners' safety, health and wellbeing can be improved by New-EIR germicidal UV, air quality readings can be taken by the sensors and UV dosage can be tracked and displayed for the resident or business owner. A 30-day record report can be printed out for visitors, business customers and government inspectors. The user, through the user interface app, can set the device to be turned on/off manually or to automatically turn the UV-C on/off when the indoor air reaches the user set TVOC levels l.

The indoor air quality will be measured by a digital metal-oxide gas sensor (SGP30 by Senirion). This sensor uses a micro hotplate to heat air samples and measures the resistance of the multi-pixel metal-oxide sensor to tell how much CO2 (ppm) and TVOCs in (ppb) are in the air [32]. To get the most accurate and up-to-date readings of the whole system, the sensor will be inserted in the duct along with the light to test the air moving through the HVAC system.

Tests show that UV-C reduces the measured TVOCs in the air, but prolonged use will cause false

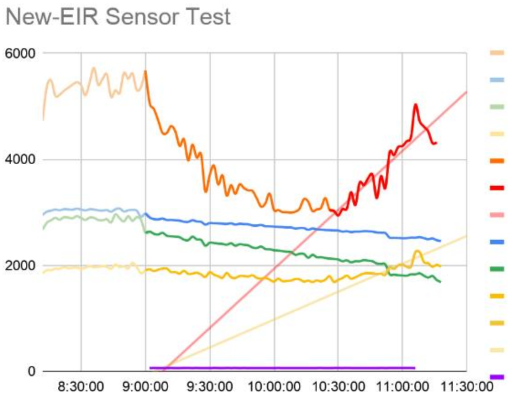

Figure IX-3 TVOCs lower by UV-C [27]

readings. In this test more than 30 minutes of readings were used a baseline before the UV light was used. Once the UV-C was used there was a significant reduction recorded by the sensor, but then false readings occurred after two hours (See Figure IX-3 TVOCs lower by UV-C). The false readings trend lines show a direct relationship to the operation of the UV-C light. This is possibly from UV-C by-produces like hydrogen peroxide (H2O2) or ozone (O3) interfering with the sensor. Ozone has an odor but was not noticeable at tested concentration. The SGP30 is sensitive to H2 molecules, so this could be the sensor detecting residual H2O2 in the air. This was more prone to happen more in smaller occupied spaces so it is very important that the UV-C light is only operating as needed with air flow and the UV-C device should not be oversized for the occupied space. Another indoor air quality sensor (CCS811) was also tested to compare results. The test showed that it can be more reliable and not affected by the UV-C. This sensor works much the same, but it is affected more by temperature and humidity. If used, we would need to use temperature and humidity readings to offset the VOCs reading. Another test showed the air quality sensors where able to sense VOCs (See Table K-1).

Other UV devices claim that the semiconductor Titanium dioxide (TiO2) can be used as a photocatalyst to chemically breakdown pollutants and VOCs [33]. One experiment showed that TiO2 irradiated by UV-A causes oxidation of adjacent VOCs converting them into CO2 and water. This happens when TiO2 absorbs a photon with high energy UV radiation. This causes an electron to move from the valence band to the conduction band, leaving behind a highly reactive positive hole in the

TiO2 enhance UV-C

30Min	Baseline	Bare Steel	TiO2 Coating
Start	14861	14883	14897
End	14839	14617	14631
% Change	0.14803849	1.787274071	1.785594415

Table IX-3 Does TiO2 enhance UV-C [27]

valence band to convert VOCs into CO2 and water and water and oxygen into H2O2 [33]. We tested the SGP30 H2 reading to detect changes in the air samples caused by UV-C and TiO2 vs. a non-reactive enclosure like Steel. After 30 minutes the control (bare steel) had a 1.7873% decrease, and the variable (TIO2 coating) had a 1.7855% decrease. While lower frequency UV might be enhanced by TiO2 our sensors did not measure any significant change caused by Titanium Dioxide to air samples irradiated by UV-C.

The UV and indoor air sensor will communicate data using Inter-Integrated Circuit (I2C) protocol. I2C allows all our devices to work on the same bus, unlike UART. Each device uses the same lines without any additional select lines like SPI. I2C allows more reliable readings than analog. I2C might be more complicated overall but it simplifies our project build by having several devices with many sensors' readings [34]..

The disadvantage of I2C is that it can only be used at close distances, less than 20 cm [34]. To connect the outdoor sensor remotely we had to use a differential I2C converter which uses fully differential Op-Amps to convert the digital I2C signal to waveforms that can be carried over Ethernet up to 30 m (100 ft). This feature has not been tested for the whole 100 ft; the greatest distance it has been tested to work at is 25 ft.

The Fully differential Op-Amps converts the clock signal (SCL) into two differential signals (+DSCL, −DSCL) and the Data signal (SDA) into two differential signals (+DSDA, −DSDA), and the waveforms are transmitted by 2 twisted pairs of conductors on the Ethernet cable, (+DSCL, −DSCL, +DSDA, −DSDA). Another twisted pair is used to power the sensors (VDDA, GND). In testing the reconstruction of the differential I2C (DI2C) signal with the original I2C signal in a digital logger the two signals were identical. (See Figure XI-1)

I2C wire color code

D0	**SCL (I2C bus clock signal)**
D1	**SDA (I2C bus data signal)**
3V3	**Bus Power 3.3 VCC**
GND	**Ground (0VDC)**

Table IX-4 I2C wire color code [34].

On the other end, the waveform is converted back to a digital I2C signal by half wave rectifiers. The conversation to differential transmission lines for I2C removes electrical noise and common-mode offsets caused by other electrical devices near the transmission line. This connection does not work the same as ethernet; any CAT-5 cable with RJ-45 connections like the ethernet cord can be used but it cannot be connected to any other ethernet device, router or switchboard without shorting out the VDDA and GND lines.

The differential I2C converter allows us to place the outdoor sensor up to 100 feet from the main controller so it can be installed outside with the solar panel. Having the outdoor sensor installed under the solar panel will make it easier to run the power wires with the ethernet cord. The outdoor sensor is housed by a small Stevenson's screen to protect it from rain and bugs but still allows for air flow.

The outdoor sensor is the Bosch BME680. It can sense temperature, relative humidity, and air pressure. It uses a small hot plate to heat sample air between 200-400°C and measures the resistance of the gases. The more air pollutants in the air the less the resistance of the gases. This resistance value is used to calculate the Air Quality Index. BME680 was tested by Bosch with 0.5-15ppm of VOCs at 20°C and 50% RH for 220 hours 700mg/m3 of Ethane, Isoprene/2-methyl-1,3 Butadiene, Ethanol, Acetone, and Carbon Dioxide. [29] This sensor can reliably record the outdoor temperature, humidity, and air sensors air quality index reading to online AQI reports show that it is not reliable to measure the outdoor air quality as required by our design metric as stated.

Testing accuracy to online readings		
Date Time	08 Feb 12:30	10 Feb 12:30
UV Index	2	3.7
VEML6075 read	2.035 ±1.5%	3.825 ±2.9%
Accuracy	98.280%	96.732%
AQ Index	52	69
BME680 reading	7.095 ±13.9%	12.865 ±12.2%
Accuracy	13.644%	18.645%

Table IX-5 Testing VEML6075 Sensor, BME680 Sensor [27]

The Air Quality Index accounts for more than VOCs. Particulate matter (ie. pollen, dust), CO2, SO2, NO2 and, Ozone (O3) are not measured by the BME680 but are factored into the normal Air Quality Index. To test accuracy of the BME680, live readings were compared to online AQI which had an unreliable accuracy of 13.644 - 18.645% (See Table IX-5). This test also compared the UV sensor UV Index reading with online UV Index reports for the same day the UV sensor was found to be 96-98 % accurate (See Table IX-5).

All sensor readings go to a 32bit microprocessor (ESP32 WROOM by Espressif Systems). The ESP32 has 520kB SRAM and 16 MB Flash Storage. The ESP32 can connect with dual-mode Bluetooth (classic and BLE) and 802.11 BGN Wi-Fi, for the user to connect to change settings and view live readings [35]. ESP32 will operate the Single Pull Double Throw (SPDT) relay to control the UV-C lamp [36]. Using a web browser or Android app., live readings can be viewed. The lamp can be turned on and off manually or the user can set the min/max level of TVOCs to automatically turn the UV lamp on and off.

With 16 MB of flash storage, data can be stored for 30 days and printed out for a 30-day report to be displayed for business visitors to know the indoor air is sanitized and safe (See Figure IX-5 Printed 30-day Report.).

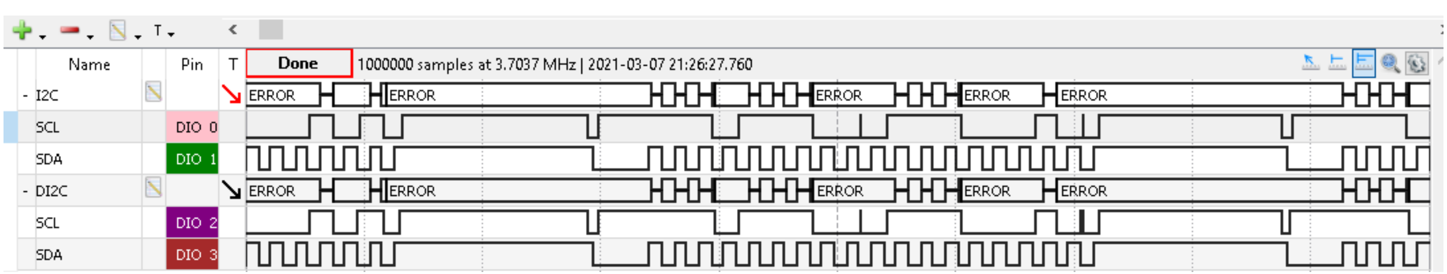

Figure IX-4 I2C and DI2C Comparison [27]

The whole device has been tested to run on a 24-volt DC plug-in wall adapter rated at 1.04 amps. For power independence it can be connected to two 18 volts photovoltaic solar panels in series. At nights, the device will be powered by 2 (12 volts, 26 amp-hour) batteries. The solar panels produce 100 Watts during the day to run the device and charge the batteries. To manage power of the microgrid we can use a PWM (Pulse Width Modulator) or MPPT (Maximum Power Point Tracking) controller to regulate the voltage and protect the batteries [37]. The PWM controls the solar panels output voltage by switching the direct current on and off with an average on and off voltage of 24 V. The times that the PWM switches off is wasted power. The MPPT is more efficient at controlling voltage and current than a PWM. The MPPT balances the power generation and consumption with recharging the batteries. With MPPT some of the excess voltage from the PV cells not used by the device during the day can be converted into current and used to charge the batteries. Figure IX-6 through Figure IX-8 show the initial power, the 12-hour mark and the final 24-hour measurement of the power through the MPPT. All three figures show the voltage. The figures show

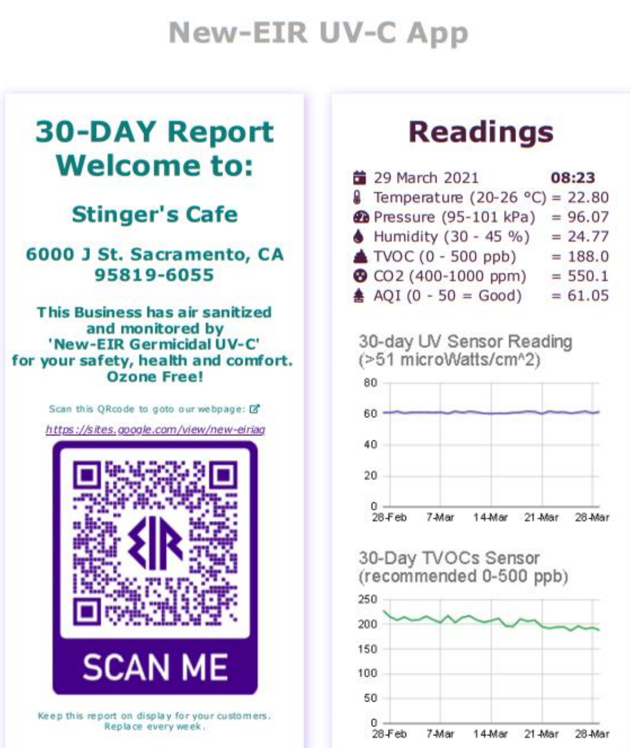

Figure IX-5 Printed 30-day Report. [27]

the battery shutting off during the night and the daytime showing "Bulk" which is the power being sent to the batteries as well as the system.

New-EIR does not work alone but needs a way to move air. If not installed in an HVAC duct, the device will need its own fan to circulate the air inside the occupied space. We will need a 24V DC fan with a capacity of 550 CFM, air filters with a rating of at least MERV13 and its own ductwork for housing the device and shielding occupants from the UV radiation.

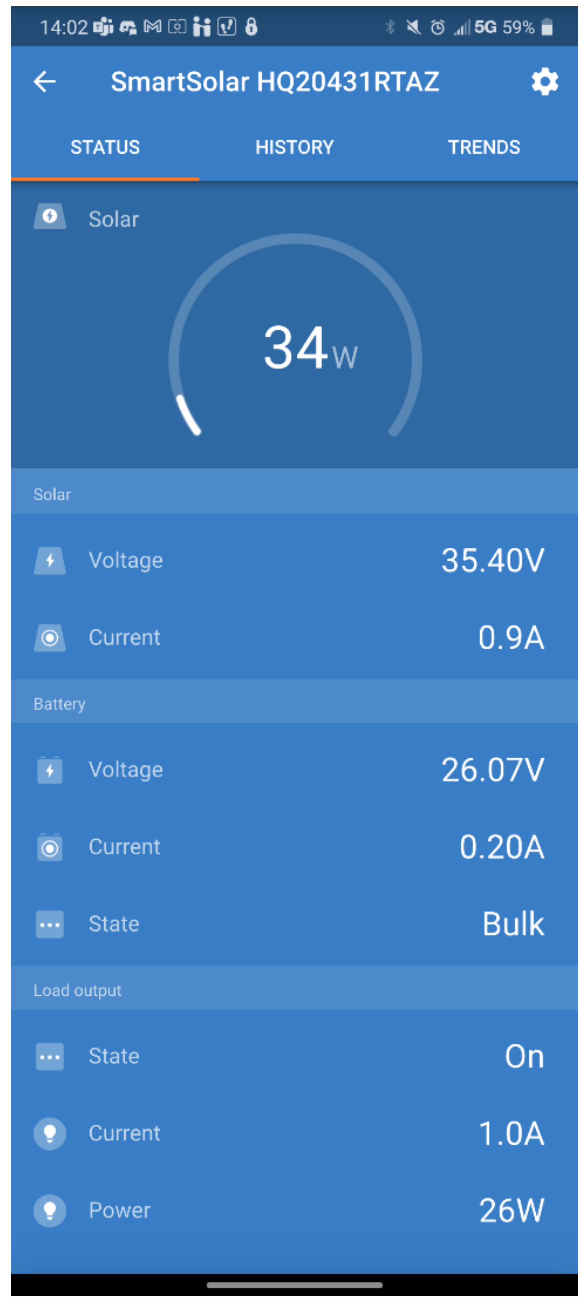

Figure IX-6 2pm MPPT Power status for the panel, the battery, and the system current and wattage. [37]

With the other components and parts of the New Eir device tested and accounted for, the last part that needed any work and verification was the Android mobile application, or just “app” for short in order to avoid redundancy. The testing for the app was split into three major parts.

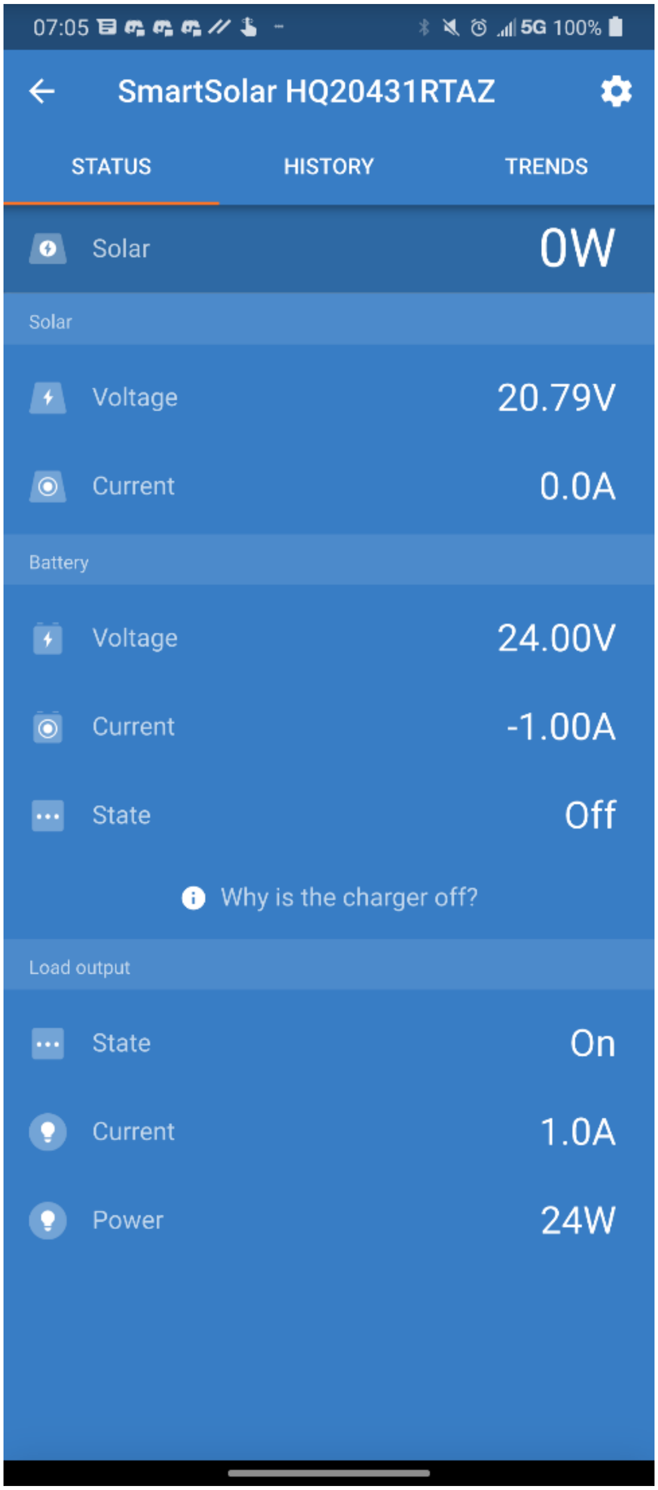

Figure IX-7 The 7am MPPT status for the panels, batteries, and system current and wattage [37]

The first was a test to see if the app would launch on its own untethered from the IDE, or integrated development environment. The first test was done with the alpha version of the app and it was found to work without much of a hitch. A few additional notes to be made about this part. It took

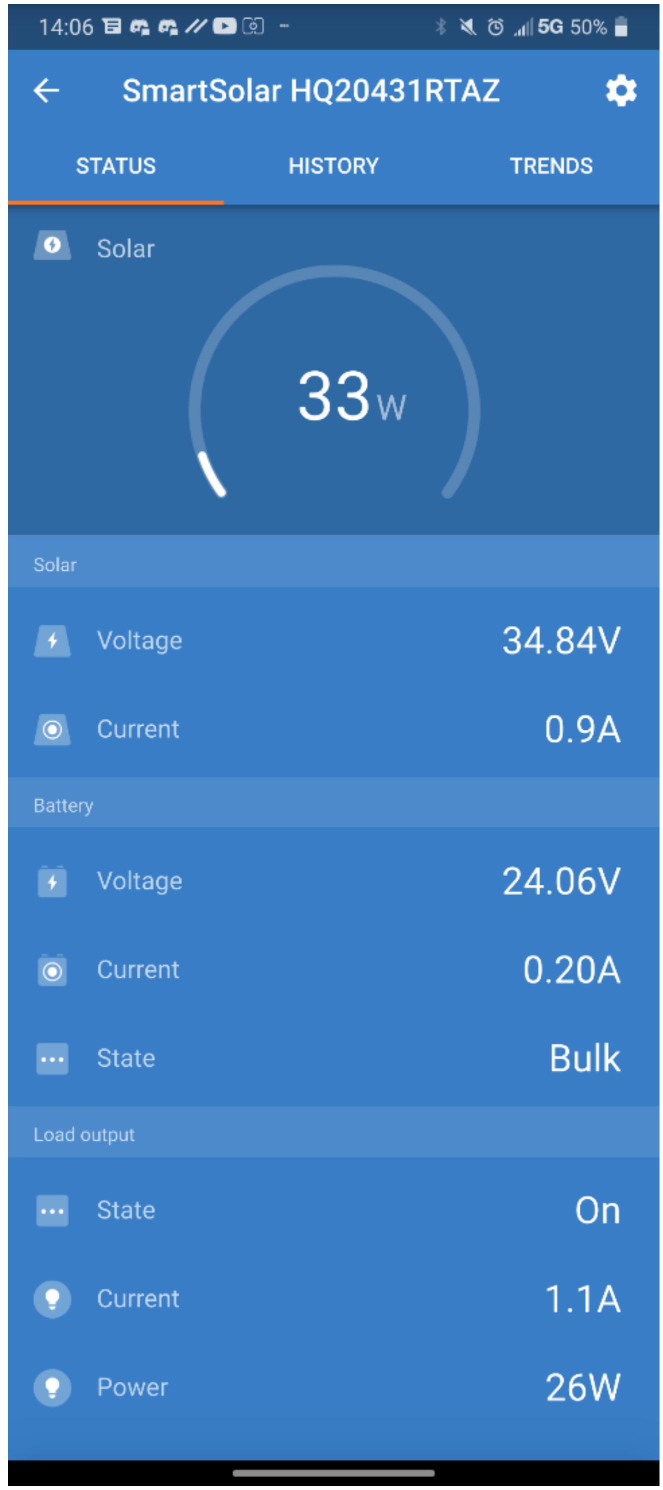

Figure IX-8 The final 24-hour status of the panels, batteries a, and the system current and wattage. [37]

about a week of reading up guides and tutorials in order to fully under how to get the app to compile, look a particular way, and load onto the phone. The one minor inconvenience that had occurred, had occurred about halfway into development of the very first test version of the app. About 50% or so through development of the test app, the developer ran into a serious bug that was not well documented online and was therefore not very easily fixed by an untrained developer. After some thought and consideration, the current version of the app was abandoned and a new app was developed, as trying to get the old version to work would have been a massive waste of time and resources. Once this hurdle had been cleared, the test app was a success and was able to launch and run on its own. The appearance of the app was not documented as it was deemed irrelevant and too much like the app that was used as a reference.

The second test was a bit more involved. The second test consisted of making the app read a CSV, or comma separated value, file and making the app update the text boxes with the most relevant information. This proved to be more involved than the first part because the first step was largely based on a tutorial provided by the team at Android Studio, the company whose IDE the developer of the app used. However, the second step proved to be much more difficult as any resources on the topic were entirely unrelated to the afore mentioned tutorial and therefore required that the developer get more accustomed to the IDE and get more accustomed to the code and how all the files interconnect and work together if he wished to have any chance of making this work. Though the reality of this test was a lot more mundane than the previous description made it out to be, this step was decently involved, just not in a way that would be interesting to anyone else who the developer would have talked to about it at the time. However, this part of the development cycle of the app was not only mundane yet involved, but also pointless as proven by the third level of test of the app. Before the third test was developed, the second test was still underway. After much reading, the developer had found a way to make it work and was able to read a CSV file that they had provided. This was a great success and was short lived come the third phase of testing.

The third test was by far the most involved and had more bugs and hiccups than the last two tests combined. The third test was a test to connect to Google Sheets and read the file with the data that our device had been collecting. This involved a few parts in the initial phase: establish a connection through Google's Sheets API, read the data from the file, and store/display the data on the app. This was the original plan and was to be worked on as soon as possible. However, the first major hiccup had reared its head. The IDE that the developer had been using, Android Studio, had some sort of indescribable internal meltdown. The IDE wasn't just having any ordinary issue. For example, had it been loading slowly, or stuttering, or crashing, those issue could and would be resolved swiftly. However, the issue had been far more severe than ever anticipated. The IDE had stopped recognizing key library functions of both Android code and crucial parts of the Java language as well. For example, the program stopped recognizing strings. This was an easy fix as all the strings could be replaced with arrays of characters. However, the larger issues, such as library functions that were crucial to the app being able to display anything, let alone start up, were not easy fixes. In fact, after much work and searching through whatever knowledge the internet had, the developer had come up empty handed. The next logical step was to uninstall the IDE and reinstall it. This had not taken too long and had been entirely ineffective. All that it had done was give the developer hope, only to have that hope crushed when the app finally compiled and reloaded all the files and returned to its original state of red scribbles and disappointment. For reference, the red scribbles were how the IDE let the developer know that there was issue with the code. The developer had taken time away from the development of the app and had returned to it a few months later. Thankfully, the team at Android Studio had finally released a version of the IDE that worked, though it was in Alpha, and the developer was able to get back to work.

After the long break, the developer had returned to trying to get the app to connect to Google's Sheets API. This process took a decent amount of time as the developer had been entirely new to the process and was relying heavily on the tutorials and guides provided by Google themselves in order to try and get the whole ordeal running. As one might expect, the developer ran into issues. In fact, much like with the previous major hiccup, the issues were great and once again no one on the internet had seemed to run into the same issues. This meant that once again our developer was stuck trying to figure his way out of a situation, he was entirely new to. After much time had passed, the developer decided to investigate alternative ways of reading Google Sheets files, as there must have been other, simpler ways of doing this. Much to his luck, there was, as he had learned, a way to turn that Google Sheets file that he had thought would be a CSV file into a JSON file. Then, this JSON file could be downloaded and read by the app on its own, meaning that there was no reason that anyone would need to connect to the Google Sheets through the API. This meant that a huge burden had been lifted and with just a few more days of work, the developer was able to not only read the file, but also display that data as a convenient list for the user to be able to reference whenever they pleased, all a click away. Those three tests were the main tests for the app and when the third test was concluded, the app was up and ready for operation.

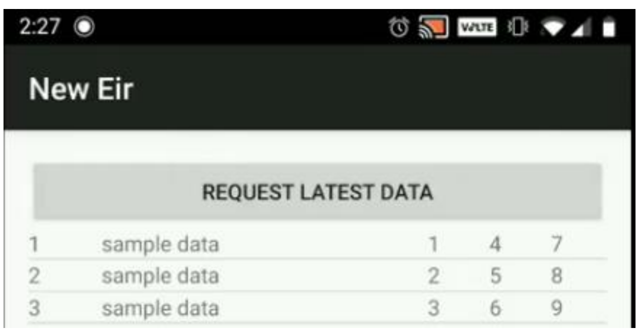

Figure IX-9 New-EIR Interface APP [38]

X. MARKETABILITY FORECAST

Airflow in public areas can quickly spread infectious airborne diseases, compromising the health and safety of the occupants. Airborne diseases like Coronavirus and Influenza can be spread via contaminated indoor air, circulated by unsensitized air conditioning. To combat the spread many governments have imposed lockdowns to reduce exposure. Concerns about safe indoor air have caused many businesses to operate at reduced capacity or remain shut down to prevent the spread of SARS-CoV-2.

New-EIR Germicidal UV-C is intended for use in indoor area like small businesses with circulated air to provide safe sanitized indoor air for occupants to conduct business. To observe the use and effectiveness of the UV installed in HVAC systems live readings can be viewed from an Android APP or web browser.

We see this device fitting into the world market of people and businesses impacted by the pandemic. We intend to market this device for use in:

- Restaurants, Theaters, Transportation hubs
- Shopping Centers, Hair and Nail Salons
- Schools, Churches, Community Centers
- Locker Rooms, Fitness and Athletic Centers
- Hotels, Dormitories and Offices

Indoor air quality alone is not a big interest to people and interest in HVAC installs and repairs increases every summer. Increased interest in germicidal UV is directly related to the pandemic. (See Figure X-1 Google Trends interest over time Though the interest is not expected to last past the pandemic once Restaurants, Shopping Centers, Churches, Theaters, Community Centers, and Offices open, long-term interest will be in facilities effected by flu season, VOC odors and IAQ. Schools, Locker Rooms, Athletic Centers, Hair and Nail Salons, Hotels, Dormitories will be more conscience of the importance of UV on good air quality.

In 1910 Marseilles, France, was the first to disinfect their drinking water using UV, sense then the germicidal UV market has expanded to air and surfaces [8]. There are many companies (i.e. Fresh-

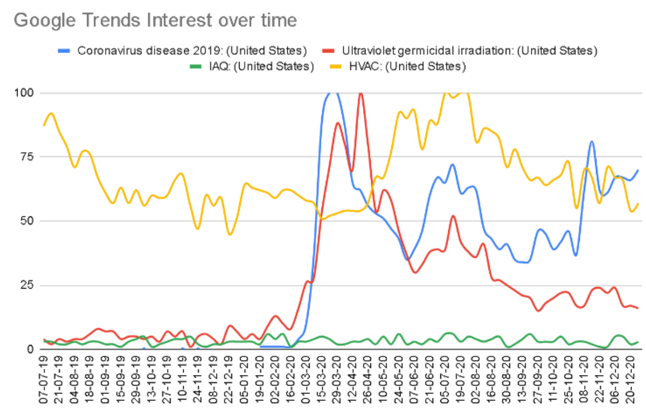

Figure X-1 Google Trends interest over time [40]

Aire UV, Steril-Aire, UVClean House), sell products with UV-A, UV-B, UV-C and ozone generating UV-V. Research valued the 2020 market to be at 2.144 billion USD and expects a CAGR of 7.8% for the next 6 years. The market value by 2026 is projected to reach 3.355 billion USD [39].

The HVAC controls market has many options for indoor air monitoring and controls from some companies like Johnson Controls Inc. whose Metasys BAC monitors temperature, humidity, pressure, CO_2 in every room. These systems are installed in office buildings, medical, industrial, and agricultural facilities across the world, but are very elaborate and costly integrate into existing systems.

In the SWOT analyses we identified our greatest strength is what makes our design idea different and unique, it is that it integrates with air quality monitoring that can be observed from a Smart device and information on sensor reading can be stored and displayed for reports. The displayed reports will also serve as good marketing. The device is easy to install and works independent of the existing control system. New-EIR is Germicidal UV-C that sanitizes indoor air and monitors air quality and UV output for business owners and their clientele. This is a new design for UV, but the pandemic has presented a good opportunity for us to try it out. Our greatest threat right now is the semiconductor chip shortage but that is starting to open the market for more companies to produce microchips. (See Table X-2 SWOT Analyses)

With COVID affecting so much, people are rightfully scared and are therefore investing in ways to protect themselves. Steve Lauten, the president and CEO of Total Air & Heat, said there is "No question that COVID-19 bumped up interest levels for UV lights.” [41] Amidst these COVID affected times, there is no doubt UV has become a very big topic, especially since it has been proven to stop the spread of SAR-COV2. More so, with people wanting indoor facilities to reopen, the “consumer interest changed not only in volume but in degree of urgency” [41]. This urgency and increased demand have opened the doors for many UVC-HVAC companies and some companies have seen incredible gains.

Table X-1 SWOT Matrix		
	Helpful	Harmful
Internal	**Strengths:**	**Weaknesses:**
	characteristics of the business or project that give it an advantage over others.	*characteristics that place the business or project at a disadvantage relative to others.*
	We are EEE and CpE	Inexperienced Students
	We can analyze the market effectively to make sure our product stands out (i.e., our system has sensors that provide the user with data, a unique feature)	Low budget
External	**Opportunities:**	**Threats:**
	elements in the environment that the business or project could exploit to its advantage.	*elements in the environment that could cause trouble for the business or project.*
	Pandemic	Competition
	Automation Controls	Chip Shortage

Table X-1 SWOT Matrix

Table X-2 SWOT Analyses		
	Strengths	Weaknesses
Opportunities	**Opportunities-Strengths Strategies**	**Opportunities-Weaknesses Strategies**
	Use Strengths to take advantage of opportunities.	*Overcoming weaknesses by taking advantage of opportunities.*
	We can use our prerequisite knowledge to make informed decisions on our product's design	Academic Resources from School
	Location: Densely populated area increases market demand Competitors: We can see where our competitors come short and adapt accordingly	Our target customer is financially struggling due to COVID-related issues, so we could focus on keeping the price down, satisfying our customers and helping us stay within budget too
Threats	**Threats-Strengths Strategies**	**Threats-Weaknesses Strategies**
	Use strengths to avoid threats.	*Minimize weaknesses and avoid threats.*
	Our youthful ingenuity and novel approaches	Reduce competition by making sure our product fits a particular niche that other companies do not deliver on
	We can order ahead and focus on not making too many promises and taking more orders than we can guarantee can be made	Use our outside resources (One of our teammates is in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)) and in-school resources (professors with helpful insight that could direct us where we need to go)

Table X-2 SWOT Analyses

XI. CONCLUSION

Deadly airborne pathogens used to only be a concern for infectious patient wards at hospitals. With the recent coronavirse pandemic, serious infections from airborne diseases is a concern for every business, school, restaurant, church, fitness center. With contenuing spikes in cases and reoccurring lock downs extra measures are neccesary to medigate the spread of airborne diseases and keep businesses open. We can take known UV-C technology used to medigate infections in hospitals to help limit the spread of infectious diseases and provide fresh, clean air for people indoors. The team created a design that would do this, and the design is simple and straightforward.

The team's design has two sensors and a main board which uses i2c controls. All the features are connected to a solar panel and battery. The sensors will be able to detect multiple air quality levels and relay them back to the board and be monitored on a smart device app. The solar panels allow for the freedom of location to off grid applications that is a main draw to the design. Streamlined software for communication with the sensors and the board will be the area the design will need the most attention. The UV-C module will sanitize the air and let us all breathe a little easier. With this being decided, the next step was funding.

The idea of this project is to have an affordable UV-C air sterilizer, so our goal is to find inexpensive parts effective in sensing necessary metrics. The parts for this workable prototype will be self-funded by members of the team. By the end of semester, the project will have a workable prototype that monitors air quality, operates a UV-C lamp, measures the UV-C output, and reports relevant information to a mobile app. The product we will be designing in the spring. It will be pricier as it includes an independent power source. The PV solar array and back-up battery supplying the power will be the largest expense. With this equipment we should be able to take UV-C used in big hospitals and have an inexpensive solution for small businesses to have clean, healthy air and stay open without spreading diseases. This project would take time to develop however, and we needed to make sure that the steps were laid out to keep us on top of them. This led to the creation of the project timeline.

A project timeline is a visualization of project deliverables. It gives an overview of the tasks and milestones from start to finish, as well as providing a schedule to help disperse time and effort. Prior proper planning prevents poor performance. Therefore, creating a project timeline is so useful to keep the team on track to meet deadlines. Without visualization of all the tasks ahead, it becomes easy to fall behind.

We created a Gantt chart to picture all events, tasks and milestones required to present a final product, as well as their duration and the team members involved. As we progress with the project, it is likely there will be some minor adjustments to the timeline or team member availability, so the chart is somewhat flexible.

The design project starts with researching IAQ, airborne pathogens and the effectiveness of UV-C radiation sterilizing airflow. Seeing that UV-C was a possible solution to unhealthy air, we started a design idea that would use air quality sensors to monitor indoor air quality and control the operation or a UV-C lamp.

We found sensors that would read the data we wanted to document. Next, we acquired a microcontroller that would be suitable to receive data from many sensors at once, in addition to having Wi-Fi capability. To ensure all the components are compatible, we tested the sensors with the microcontroller separately before starting the prototype. We also tested the connection between the microcontroller to a smart device, which will be integral in allowing the user to observe and control the device.

Once we found compatible sensors with the desirable metrics for our project, we will build a prototype for demonstration and testing. Next, we will design a module to house the equipment in for easy installation in most practical applications as a deployable product. With this we will assess its marketability and make any changes before moving on to add the final features like solar power for off grid use.

The three parts of this project the indoor equipment, which will be housed in one module, the outdoor equipment, which will be in a separate module, and smart device app and will be used to build an initial prototype at the end of Fall Semester. The outdoor module will communicate with the microprocessor via ethernet cord using differential converters to send the i2c data longer distances. The smart device app will communicate with the microprocessor via the built-in Wi-Fi of the ESP32 to interface with the user. All of these things do come with risks however, so we needed to account for those.

We see this project having a low amount of risk considering the fundamental aspect of germicidal UV-C is not a new technology and our method of integrating it with IAQ monitoring and a user app increases its versatility and reliability even without the threat of COVID-19. Even at low risk of failure, problems that are not addressed can jeopardize a project and even certain failure can be attenuated with good foresight, contingency planning and diversification. We acknowledge that the best remedy to most problems is clear communication within the team. Getting the hardware where it belongs on time is the key to keeping the timeline while socially distanced.

The risk assessment section discussed the plans the team made to combat unpredictable but realistically possible project events that will cause severe to mild delays. The mitigation prepared for each eventuality was also included in the timeline projections for the tasks that are affected by the delays. The strategies in place for the more severe and more likely events focus on fast response to the occurrence, having our own and outside resources prepared to deal with incorrect parts being sent, design flaws when it comes to part housing, and measurable metric recalibration for the features created at the early stages of the design. The amount of communication needed for each involved for each uncertain event depends on the level of probability the team members all agreed it would have. The higher probability risks, no matter the effect it would have on the design timeline, are constantly brought up by the and remain a focus for the group. Other less likely events remain in the dialogue, but their occurrences are a lower focus for the group so have plans but are not mentioned in each meeting. The least likely to occur have been discussed and plans made but no updates on them are constantly needed, such as parts becoming damaged or arriving in that state, team members becoming unavailable, as well as complete loss of research and the report, and the real but low chance of a natural disaster displacing the team.

The plans we have for each situation are constantly communicated to each member for the more severe and likely events. The measurable metrics of the design features not being met is a large delay to the progress of the project. The likelihood of it occurring is high therefore our team placed high value on having it constant energy added to its mitigation. Once one of the metrics is not met the team will be immediately made aware, a discussion made to locate the problem that may be causing the issue for the metric and use full resources to change the part if needed or evaluate the metric with a professor's approval and still maintain the integrity of a decent design. The measurable metrics may also convert to flaws in the design and changes that are needed. This is one of the most likely events a project will see along with the need to social distance and incorrect part. Our team negates them using over-communication. The constant sharing of our knowledge and resources is the best way to combat the most likely delays to the design.

The design also sees less likely delays in power miscalculations. It can result in the battery not charging the way it needs to meet measurable metrics of the unique design features. It can also cause damage to parts or not power sections correctly. A delay in powering all the parts of the design will cause severe delays. Other similar occurring events with close impact that have similar to more severe delays to the design are handled similarly as power issues. Teammate burnout, COVID 19, code issues, and component compatibility issues are close to the same likelihood as the power miscalculations. The team has open communication to combat the burnout and any results from COVID 19, outside resources that can help once we meet with a coding issue and compatibility between separate parts of the project.

The least likely events of the risk assessment chart also have their own plans made by the team to address them as soon as they come up, but the team focuses less energy into their importance due to the low likelihood of occurring. Parts becoming damaged can be changed quickly from ordering the same part as soon as it becomes damaged. The IAQ sensor burning out would be an example but with more sensitivity to occur. The communication being open allows for other members working on tasks that involve the broken parts to allow for the delays to happen and have the time delay prepared work wise. We all concluded that a natural disaster displacing team member or a team member becoming unavailable both have low chances but need plans. If a natural disaster were to occur the project most likely would become moot. A team member being unavailable means again that the team needs to adjust for them being missing and therefore move the work around for the members to do. Some of this work includes testing sensors.

Testing the sensors independently showed that we had effective sensors for a prototype that could sanitize indoor air and neutralize air-borne polutants. Testing the prototype with all the sensors integrated together showed that the less expensive choise for indoor air quality sensor was not reliable to measure TVOCs and CO2 with UV-C application but could detect UV-C by-produces in the air. The other choise for IAQ sensor is more reliable at measuring TVOCs and CO2. It can also measure indoor temperature, humidity and air pressure. With everything working, what mattered next is marketability.

This market forecast is a projection of numbers, characteristics, and trends in our target market. It looks at market value, inspires reality checks, reviews the target audience, and helps visualize volume. We did research on our competition to find out their strengths, weaknesses, and position within the market, and tried to gauge where we would fit in, and who we would be likely to service. The industry overview shows the direction businesses are expected to develop the market.

We defined our target market and found research that showed a projection for a serious market expansion due to health concerns in the general public. Prices for comparable products and services are not readily available on a website because they are variable based on the individual consumer's needs. Research of demographics showed a very specific target customer, which could limit our buyers, but make it easy to tailor our advertisements for best results. The location of our customers will likely be local early in our development. Defining the Psychographics of our potential customers was difficult to the untrained team members, however research showed consistencies in their situations provoke similar thinking patterns which we may appeal to.

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SPECIALIZED TERMS

Building Envelope — All the external materials of a building, which enclose the internal space (e.g., windows, walls, and roof)

Building-Related Illness — Diagnosable illness with symptoms attributed to building indoor air pollutants (e.g., Legionnaire's disease, pneumonitis, asthma).

Conditioned Air — Air that has been filtered heated, cooled, humidified, or dehumidified to maintain the "comfort zone" of the enclosed space

Dampers — Ventilation control armature that varies open and closed to direct airflow.

Disinfectants — One of three EPA registered antimicrobials safe for health uses in public areas. EPA considers an antimicrobial to be a disinfectant when it destroys or irreversibly inactivates infectious or other undesirable organisms, but not necessarily their spores. EPA registers three types of disinfectant products based upon submitted efficacy data: limited, general or broad spectrum, and hospital disinfectant.

Essential Services — jobs critical to infrastructure operations of the community

Exhaust Air — Air mechanically removed from a portion of a building.

Heat Exchanger — System device used to allow the transfer of heat between two separated fluids of different temperatures.

Make-up Air — Outdoor air brought into a building through its ventilation system that has not previously been circulated through the enclosed space.

Mechanical Ventilation — Airflow produced by mechanical means of a fan

Natural Ventilation — Airflow produced though an opening such as a window without mechanical means.

Negative Differential Resistance — A nonlinear relationship between voltage and current, where during operation, an increase in current through the electric device causes a decrease in voltage across it.

Negative Pressure — Condition of inside air pressure being lower than outside air pressure produced by more airflow being exhausted from an enclosed space than supplied.

Positive Pressure — Condition of inside air pressure being higher than outside air pressure produced by more airflow being supplied to an enclosed space than exhausted.

Photocatalysis — A chemical reaction aided by energy from light.

Photocross-linking — A photochemical reaction of producing covalent bonds between two molecules or between two parts of one molecule.

Photodimerization — A photochemical process of adding two like monomer molecules.

Photohydration — A photochemical reaction causing the addition of water to double or triple bond organic molecules.

Photosplitting — A photochemical reaction of breaking down molecular bonds.

Re-entrainment — Exhaust air that has reentered a building by natural or mechanical means.

Sanitizer — One of three EPA registered antimicrobials safe for health uses in public areas. EPA considers an antimicrobial to be a sanitizer when it reduces but does not necessarily eliminate all the microorganisms on a treated surface. To be a registered sanitizer, the test results for a product must show a reduction of at least 99.9% in the number of each test microorganism over the parallel control.

Sick Building Syndrome — Term sometimes used to describe situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified. The complaints may be localized in a particular room or zone or may be spread throughout the building.

Soil Gases — Gases such as radon, volatile organic compounds that enter a building from surrounding sub surfaces.

Stack Effect —Pressure-driven airflow produced by convection currents inside walls as warmer air rises and cooler air descends, creating positive pressure at the top and negative pressure at the bottom structural walls that can overpower the mechanical system and disrupt ventilation designs.

Static Pressure — Stable condition of air flow produced by an equal amount of air supplied to and exhausted from a space.

Sterilizer — One of three EPA registered antimicrobials safe for health uses in public areas. EPA considers an antimicrobial to be a sterilizer when it destroys or eliminates all forms of bacteria, fungi, viruses, and their spores. Because spores are considered the most difficult form of a microorganism to destroy, EPA considers the term sporicidal to be synonymous with "sterilizer."

Ultraviolet Light – light emitted within wavelengths of 200 to 400 nm.

Ventilated Air — The total flow of air distributed throughout a building by means of louvered vents and duct work.

Visible Light – Wavelengths of light visible to humans (380 – 720 nm).

Volatile Organic Compounds (VOCs) — Gaseous compounds that evaporate from many common housekeeping, maintenance, and building products made with organic chemicals. These vapors are released during used and storage. High levels of VOCs have been known to cause the following: eye, nose, and throat irritations, headaches, dizziness, visual disorders, memory impairment and even cancer. There are many identified VOCs with different threshold limits the total amount in the air is collectively identified as Total Volatile Organic Compounds (TVOCs).

ACRONYMS

ASHRAE: — American Society of Heating, Refrigerating, and Air Conditioning Engineers

CO2: — Carbon-dioxide

CO: — Carbon-monoxide

CDC — U. S. Center for Disease Control

DNA — deoxyribonucleic acid

EPA — U. S. Environmental Protection Agency.

ETS — Environmental tobacco smoke

IAQ — Indoor air quality

HEPA — High efficiency particulate arrestance

HVAC — Heating, ventilation, and air conditioning.

HAIs: — Healthcare associated infections

HVAC: — Heating, Ventilation, Air Conditioning

kPa — kilopascal

MERV — Minimum Efficiency Reporting Values

nm — nanometer

O2: — Oxygen

OSHA — Occupational Safety and Health Administration.

RELs — Recommended Exposure Limits

SBS — See "Sick Building Syndrome."

TLVs — Threshold Limit Values

TVOCs — Total Volatile Organic Compounds

UV-A — Ultraviolet range from 315 to 400 nm

UV-B — Ultraviolet range from 280 to 315 nm

UV-C — Ultraviolet range from 200 to 280 nm

UV-V — Ultraviolet range from 100 to 200 nm

UVGI: — Ultraviolet Germicidal Irradiation

VOCs — See "Volatile Organic Compounds."

$\mu W/cm^2$ — microwatt per centimeter squared

WHO — World Health Organization

APPENDIX A.
User Manual

Figure A -1 New-EIR User Manual Cover

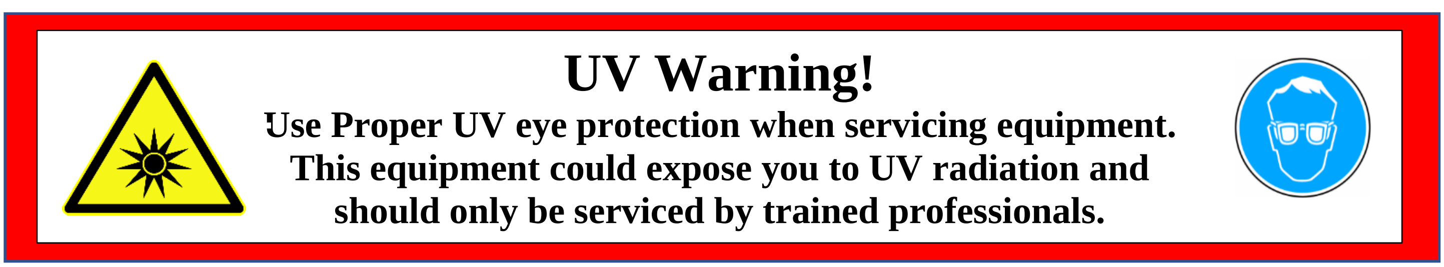


Figure A-2 New-EIR UV warning

ABOUT THIS PRODUCT

New-EIR is Germicidal UV-C that is easy to install, monitors your indoor air quality, and sterilizes airborne pathogens like influenza and coronavirus.

The high energy radiation of UV-C causes photochemical reactions in microbial DNA & RNA. This change damages the genes, preventing dangerous viruses from reproducing and infecting humans. UV-C disinfection is a reliable alternative to chemical disinfection due to the increase of chemical-resistant microorganisms and the emission of harmful byproducts from the chemicals used for disinfection. Also, UV-C breaks down volatile organic compounds without producing ozone, something UV-V cannot do. According to the American Lung Association, “exposure to ozone causes a variety of adverse health effects, even at levels below the current standard.”

New-EIR Germicidal UV-C uses 24VDC Ultraviolet light to sterilize air-borne microbes and neutralize volatile organic compounds (VOCs). The New-EIR module monitors your air quality with air sensors (carbon dioxide, VOCs).

UV WARNING!

Use Proper UV eye protection when servicing equipment. This equipment could expose you to UV radiation and should only be serviced by trained professionals.

Photo-keratoconjunctivitis: Inflammation of cornea and conjunctiva after exposure to UV radiation.

SPECIFICATIONS

1) Improves Indoor Air Quality
   a) UV-C lamp neutralize VOCs & sterilize microbes in the air
   b) UV-C reduces volatile organic pollutants from indoor air.
   c) UV-C at 254nm produces no ozone
2) Automated operation
   a) Microcontroller with i2c serial connection to sensors and Wi-Fi built
   b) Light operated by STDP Relay
   c) Measures UV output
   d) Tracks time used
3) Android App to display Indoor Air Quality for Smart Devices on Wi-Fi.
   a) Display TVOCs from airborne pollutants
   b) Display CO2 from occupants’ activity
4) Android App to display outdoor environmental data for Smart Devices on Wi-Fi.
   a) Display Outdoor Temperature, Air Pressure (normal atm.101.325 kPa), Relative Humidity, and Air Quality Index
5) Power source independent of electrical grid with 24 hour back-up power
   a) Primary power source: solar P.V. cell array: 24 Volts, 20Watts
   b) Back-up power source: Battery 24 Volts, 10-20 Amp-Hours

- **UV lamp**
  - Low-pressure Mercury Vapor Lamp
  - Quartz Sleeve UV transmittance greater than 90%
  - 24 VDC, (425 mA)), 17 Watts, 10,000 Hours life, 51µW/cm2 at 1 meter

- Higher germicidal efficiency; nearly all output at 254 nm

- **ESP32 WROOM**
    - Xtensa® dual-core 32-bit LX6 microprocessor
    - Up to 240 MHz clock frequency
    - 16MB of flash storage
    - 520 kB internal SRAM
    - Integrated 802.11 BGN WiFi transceiver
    - Integrated dual-mode Bluetooth (classic and BLE)
    - 2.3 to 3.6V operating range
    - 21 GPIO
    - 8-electrode capacitive touch support
    - Hardware accelerated encryption (AES, SHA2, ECC, RSA-4096)
    - 2.5 µA deep sleep current

Sensors

- TVOC Output Signal
    - Output range: 0 ppb to 60,000 ppb
    - Resolution: Avg. 13 ppb. Refer to datasheet for specifics
- CO2 Output Signal
    - Output range: 400 ppm to 60,000 ppm
    - Resolution: Avg. 11 ppm. Refer to datasheet for specifics
- Relative humidity
    - Operating range: 0% to 100%
    - Absolute Accuracy: ±3%RH
    - Resolution: ±0.008%RH
- Temperature
    - Operating range: -40°C to +85 °C
    - Absolute Accuracy: ±0.5°C to ±1.0°C
    - Resolution: 0.01°C
- Pressure
    - Operating range: 300 hPa - 1100 hPa
    - Relative accuracy: ±12Pa (25°C to 40°C @ constant RH)
    - Absolute accuracy: ±60Pa (0°C to 65°C)
    - Resolution: 0.18PA, highest oversampling
- UV
    - UVA Resolution: 0.93 counts/µW/cm2
    - UVA Resolution: 2.1 counts/µW/cm2

Power

- Solar Panels
    - Primary power source: solar P.V. cell array: 24 Volts, 30 Watts
- Power management
    - Maximum Power Point Tracker
- Batteries
    - Backup power source: Battery 24 Volts, 10-20 Amp-Hours

PARTS AND ACCESSORIES

1 – New-EIR module	6 × 6 × 4
1 – Remote Outdoor module	1 × 2 × 1
1 – Ethernet cord	25 feet
1 – Low Pressure Mercury Vapor UV-C Lamp	14 inches
1 – Solar Panel	24VDC, 100W
2 – Lead Acid Wet-cell Batteries	12VDC, 10AH

INSTALLATION

This dosage of UV-C light sterilizes bacteria, fungi, viruses, and their spores by damaging molecules like nucleic acids and outer surface proteins, making the microbes incapable of performing the processes it needs to survive.

Placing germicidal UV-C inside an HVAC system provides disinfection of ductwork and all the air circulated throughout the building without exposing occupants to UV radiation. UV light can molecularly breakdown volatile organic compounds (VOCs) that cause indoor air pollution. These VOCs come from commonly used cleaner and adhesives used inside.

HVAC system components like cold Evaporator Coils are covered with condensing moisture from the air which are known for harboring microbes inside its densely packed coil fins. Exposure to wavelengths shorter than 320 nm is most effective in causing this condition. The peak of the action spectrum is approximately 270 nm.

This device should be installed with the New-EIR module attached to rigid HVAC duct.

To attach the New-EIR module to rigid ductwork downstream of the air handler unit:

1. Cut a 3-inch diameter hole in the side of the rigid ductwork with at least 3-feet of straight air flow.
2. Place the New-Eir module to the side of the rigid ductwork with the indoor sensors inserted inside the ductwork.
3. Insert the indoor sensors inside the ductwork with the airflow moving between the lamp and the sensor.
4. Insert the 17-Watt UV lamp inside the New-EIR module and connect the ballast.
5. Then connect the ethernet cord from the New-EIR module to the Remote outdoor air sensor.
6. Then install solar panels and connect plug to the DC Jack.

To install the solar panel with remote outdoor air sensor attached to the underside:

1. Select an area with direct sunlight unobscured by shade from trees or buildings.
2. Mount the solar panels facing the sun with an angle appropriate for your location’s latitude.
3. Then connect the ethernet cord from the New-EIR module to the Remote outdoor air sensor.
4. Then run the power cord from the solar panel to the DC Jack on the New-EIR module.

OPERATION

Once New-EIR is installed and has power, the Red LEDs on the sensors will light up. Then the Blue LED on the ESP32 microcontroller will have a short strobe of 5 flashes to indicate that the program has loaded then it will have a short flash to indicate it is still operating normally every 5 minutes.

Connect New-EIR to Wi-Fi using your routers network ID and password. New-EIR will display the 30-Day Report at the local IP address (192.168.1.40) Enter the IP address (192.168.1.40) into your web browser on your computer or smart device. You can read live sensor measurements from the web browser and print a 30-Day report for business guests and clientele. (See Figure Below) The UV lamp can be operated manually by selecting “ON”, “OFF” or automatically by selecting “AUTO” from the drop-down menu at the bottom of the screen. More information can be found at https://sites.google.com/view/new-eiriaq

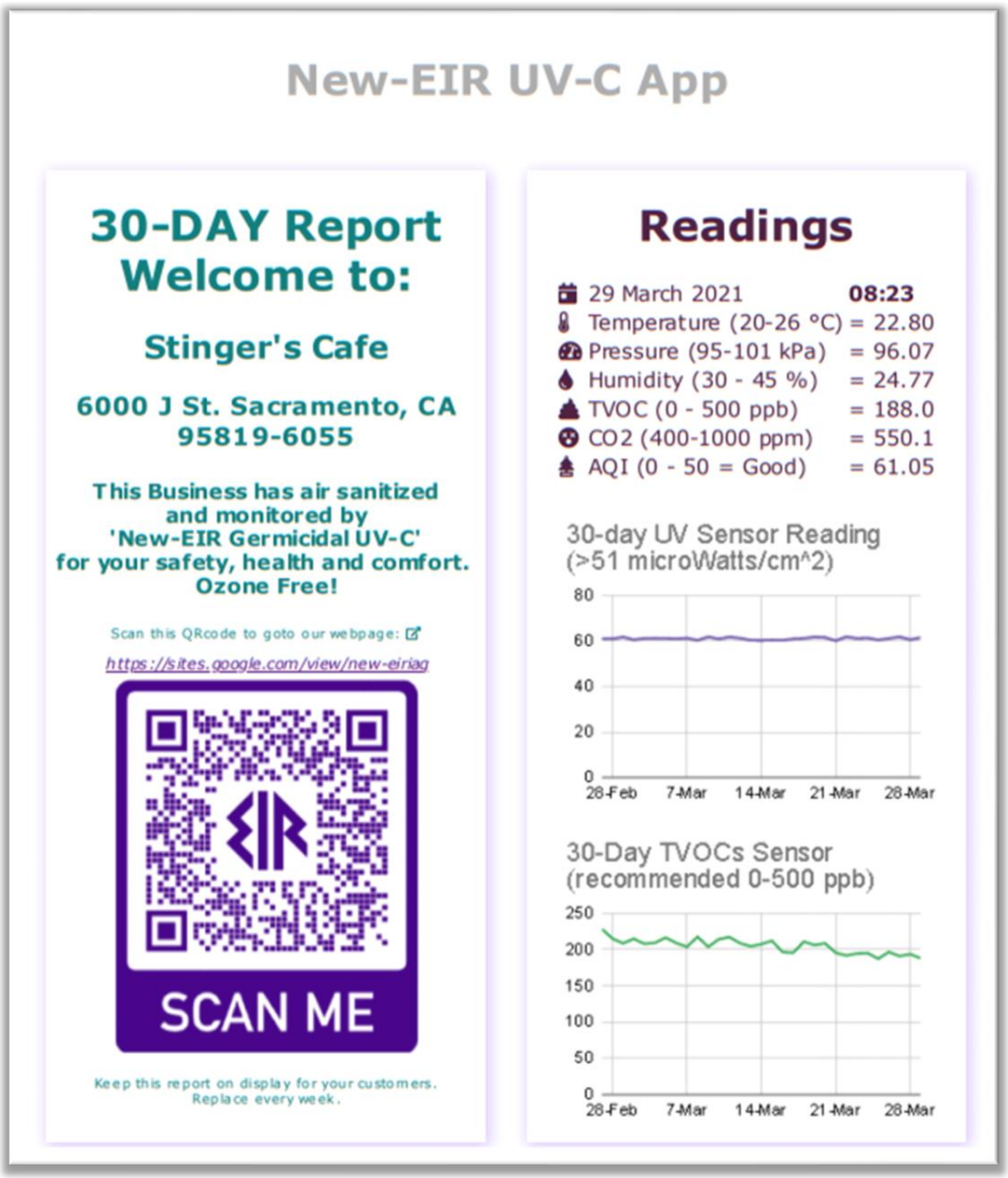


Figure A-3 New-EIR 30-Day Report

APPENDIX B.
Hardware

Table B1
Specific parts with measurable data

SKU	Qty	Name	Price (U	Specific Feau	Temperature	Humidity (RH	Pressure (101	CO2 (1000-20	TVOC (200-50
SEN-15089	1	SparkFun UV Light Sensor Bre	7.50	UV-C 254nm (50-100mW/cm^2), 200–370 nm					
SEN-16531	1	SparkFun Air Quality Sensor -	19.95					400 - 60,000 p	0 - 60,000ppb
SEN-16466	1	SparkFun Environmental Sen	18.95		-40°C - +85 °C	0% to 100%	300hPa - 1100hPa		
SEN-14348	1	SparkFun Environmental Con	0		-40C - 85C	0--100%	30,000Pa - 11	400 - 8,192 pp	0 - 1,187 ppb
SEN-15050	1	SparkFun Triad Spectroscopy	0	28.6 nW/cm2 @ 405nm					
SEN-15103	1	Particulate Matter Sensor - S	0	PM (1 µg/m^3, 2.5 µg/m^3, 4 µg/m^3, and 10 µg/m^3)					
KIT-15081	1	SparkFun Qwiic Cable Kit	7.95						
WRL-15663	1	SparkFun Thing Plus - ESP32 W	20.95						
COM-15093	1	SparkFun Qwiic Single Relay	11.95						
BOB-14589	2	SparkFun Differential I2C Bre	21.9						
PRT-09914	1	JST Jumper 2 Wire Assembly	0.95						
PQDE6W-Q2	1	5Vdc power supply	20.61						
PJ-065B	1	PJ-065B DC Barrel Jack Mount	2.15						
GPH357T5L/	1	17Watt UV-C lamp	29.63	24V 17W 253.7nm UV-C bulb					
PSM1GPH1	1	Lamp Ballast	29.95						
	1	4-pin base	3.95						
	1	24V 20W Solar panel	74.83						
	2	12V 10AH Battery	34.98						
		UV reflective Paint							
		$	306.20						

Table B-1 Specific Parts with measurable Data [27]

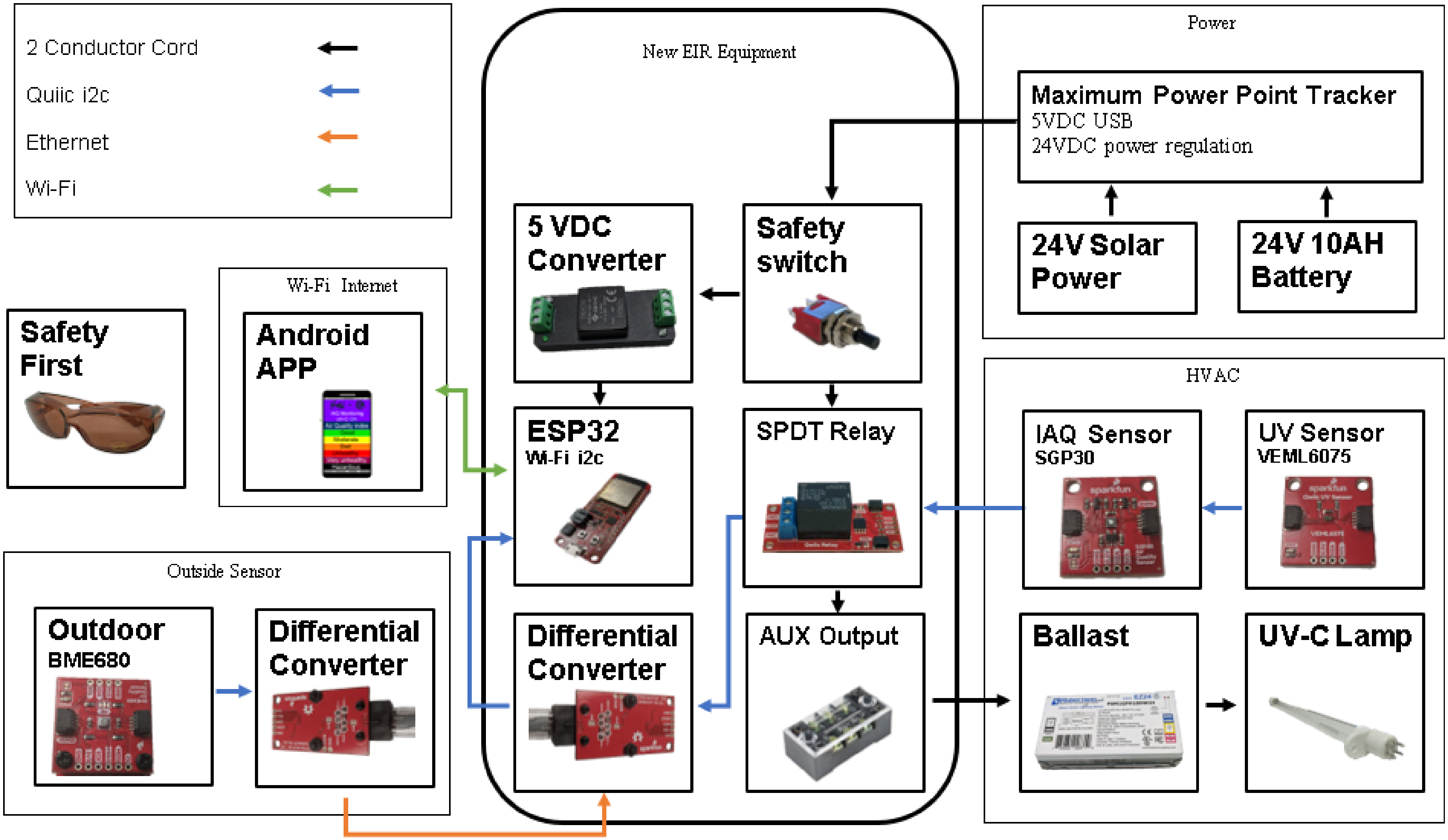


Figure B -3 New-EIR Hardware Connections[30]

New EIR Hardware AutoCAD Blueprint

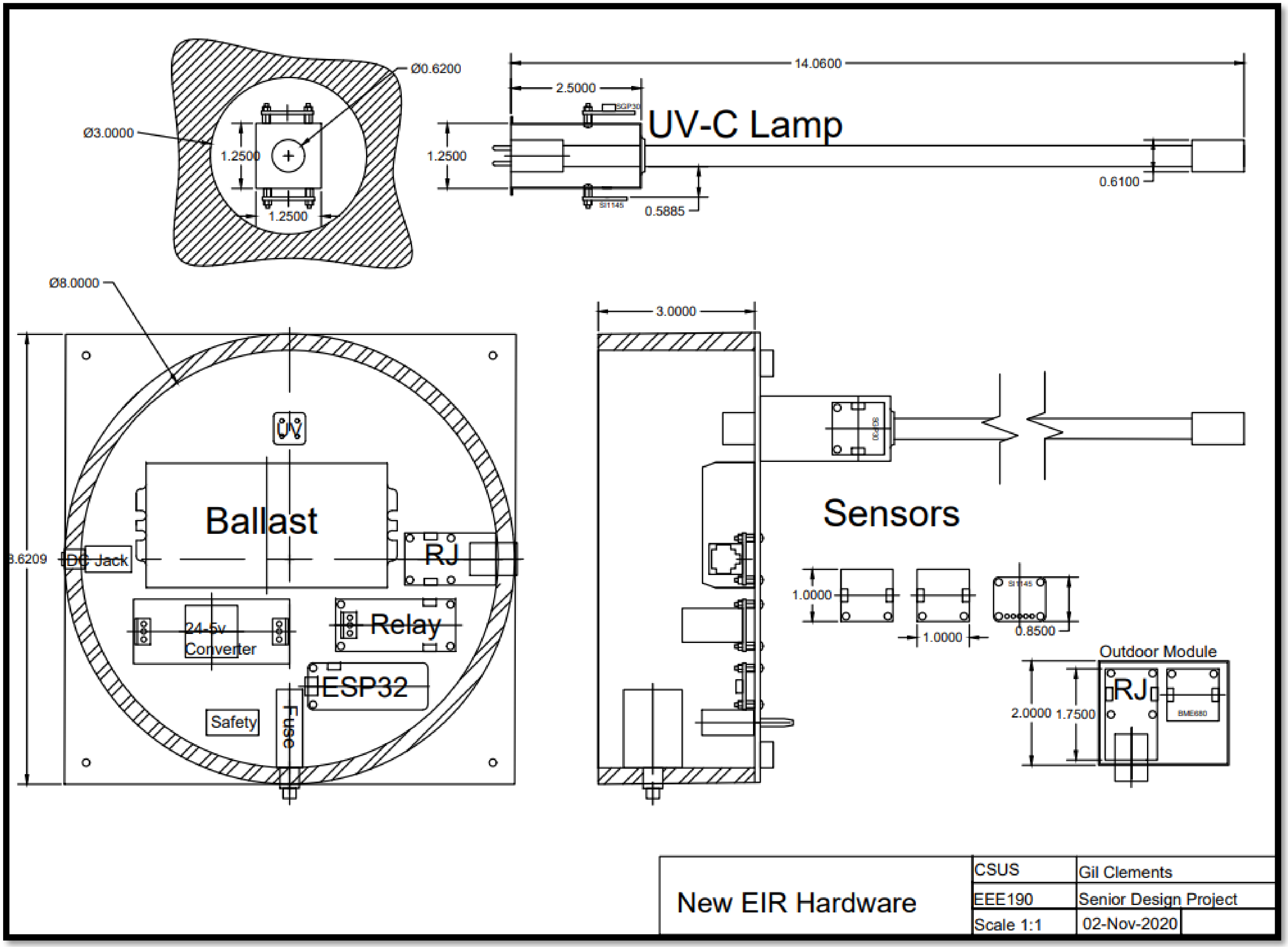


Figure B -4 New-EIR Hardware CADD [30]

Hardware Wiring and Connections

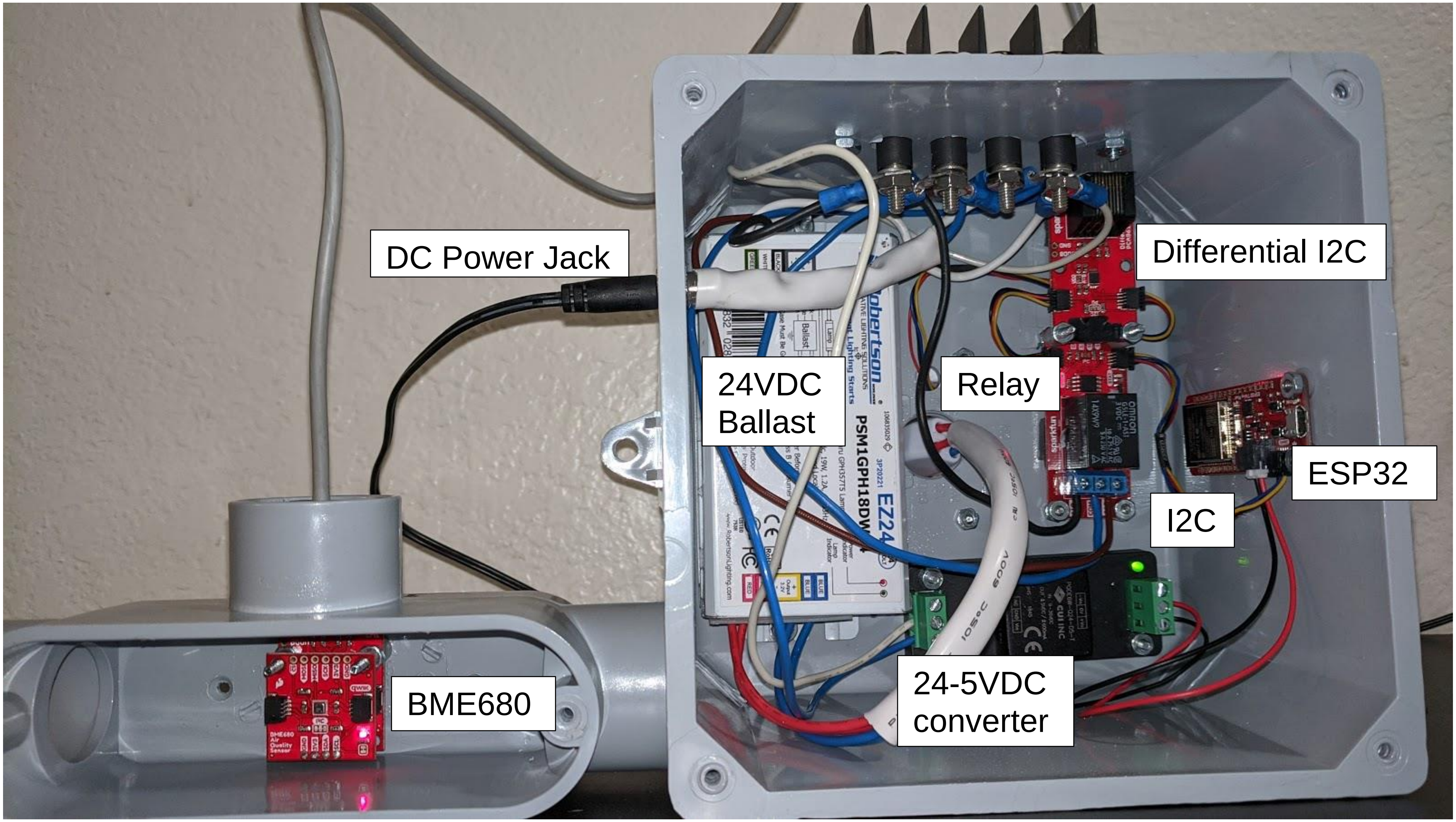


Figure B-3 Inside Prototype Hardware [30]

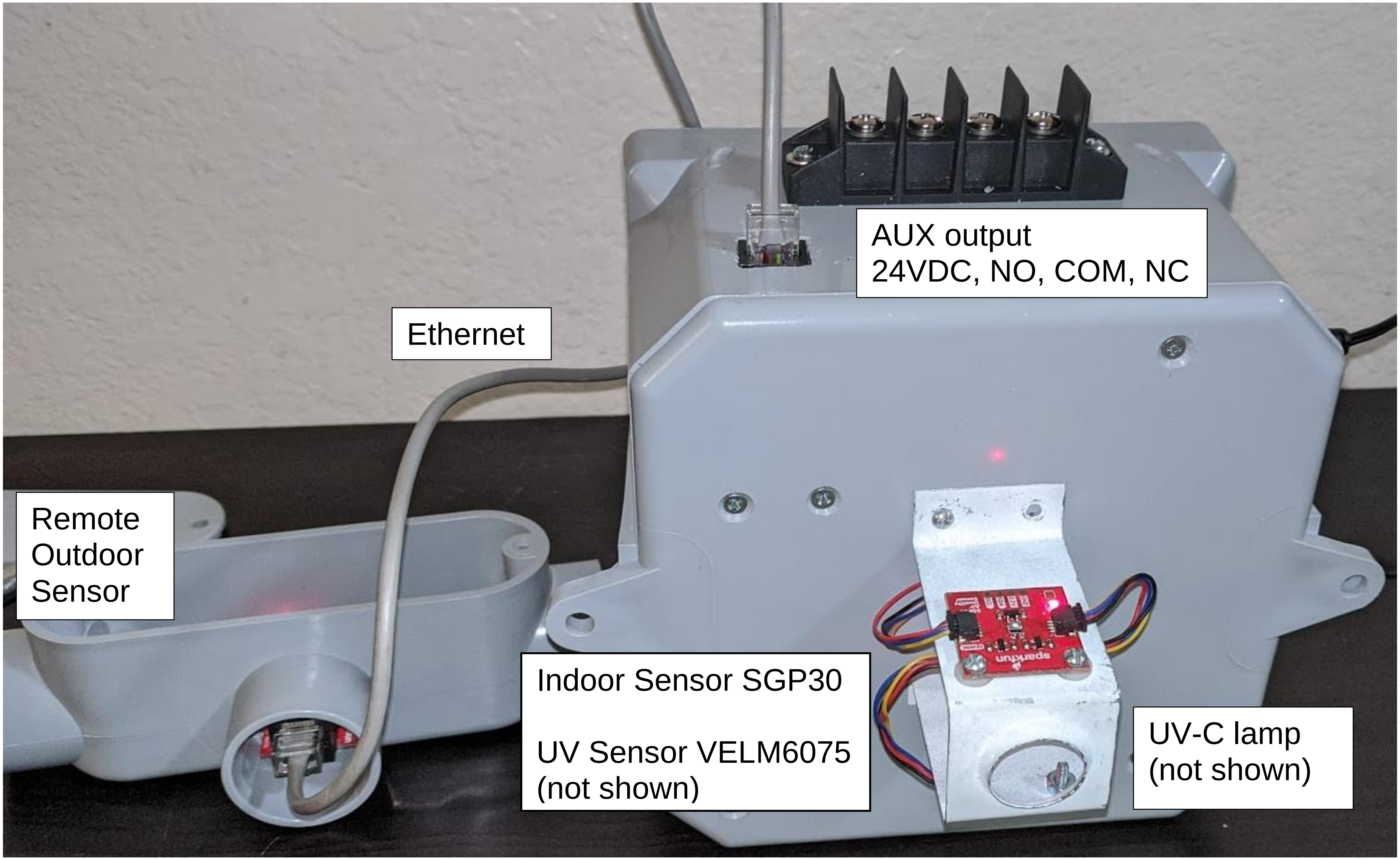


Figure B-4 Outside Prototype Hardware [30]

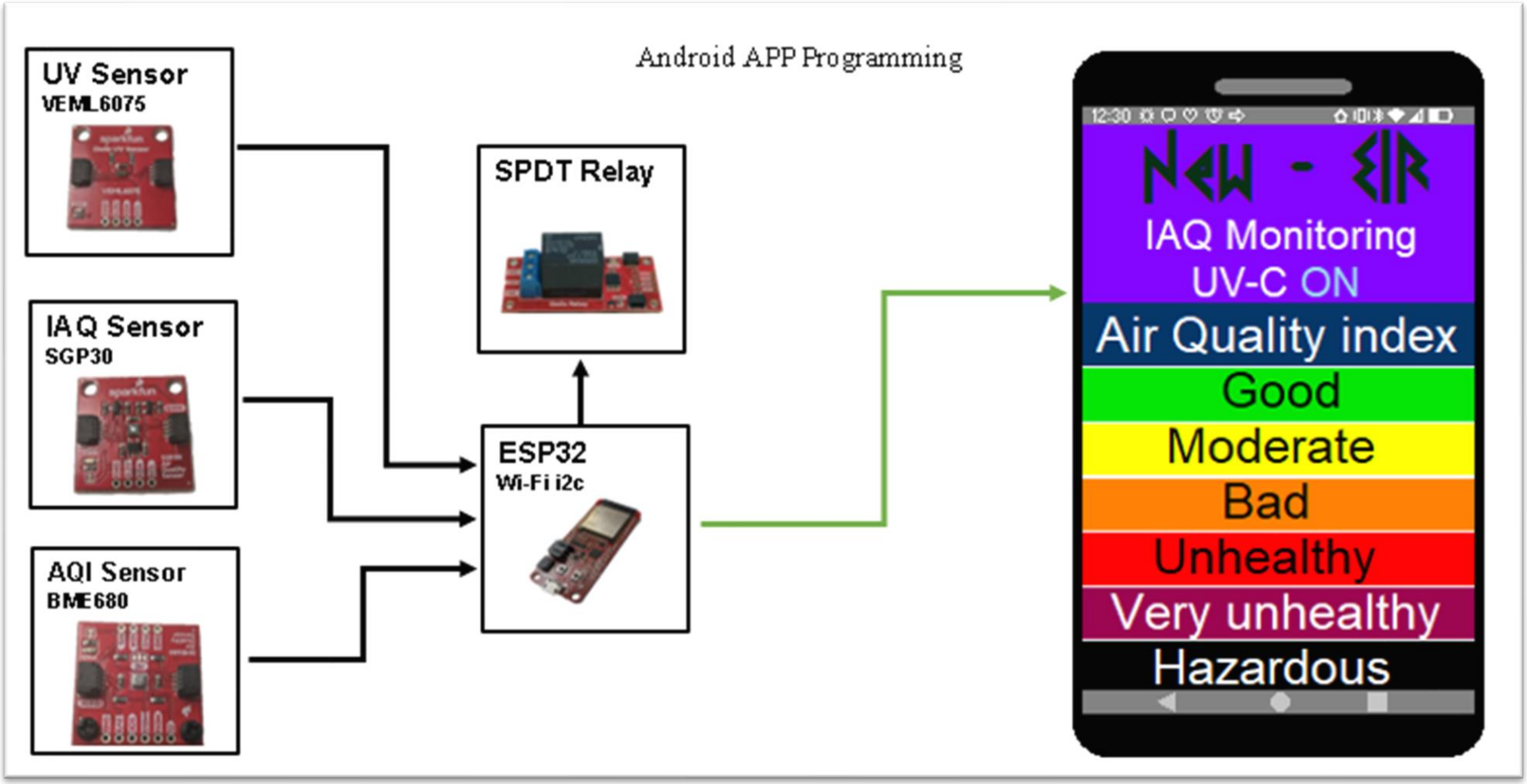


Figure B-5 New-EIR APP Connection [30]

APPENDIX C.
Software

```
#include <Wire.h>
#include "time.h"

// https://www.arduino.cc/en/Reference/EEPROM
// Memory where data can be stored even when power is off.
#include <EEPROM.h>

// WiFi ID, pwd, port number.
#include <WiFi.h>
const char* ssid = "network";      // Replace "network" with network ID
const char* pwd  = "password";    // Replace "password " with network password
WiFiServer server(80);  // port


// Adafruit Unified Sensor (used for all Adafruit sensors)
#include <Adafruit_Sensor.h>

// Sensor of temperature, pressure, humidity.
#include "Adafruit_BME680.h"

// Turn on or off high voltage device (110V).
#include "SparkFun_Qwiic_Relay.h"

// TVOC and CO2 sensors.
#include "SparkFun_SGP30_Arduino_Library.h"

// UV sensor.
#include <SparkFun_VEML6075_Arduino_Library.h>

// Instantiate device objects.
#define RELAY_ADDR 0x18
Qwiic_Relay relay(RELAY_ADDR);

Adafruit_BME680 bme;  // Pressure, Temperature, Humidity

SGP30 tvoc_co2;

VEML6075 uv;
```

```
// Control and operating variables.
unsigned long timeout = 2000;  // assume WiFi client message is done if no more characters come in this number of milliseconds
int  client_refresh   =    3;  // seconds between refresh of client (minimum=3)
int  header_interval  =   20;  // header rewritten to serial output after this many lines
int  serial_interval  =    3;  // seconds between serial output of sensor values  (minimum=2)
uint16_t relay_on_tvoc  = 40;  // relay on AUTO turns on  if TVOC is above this value
uint16_t relay_off_tvoc = 30;  // relay on AUTO turns off if TVOC is below this value

const char* ntpServer = "pool.ntp.org";
const long  gmtOffset_sec = (-8) * 3600;  // Pacific is 8 hours behind GMT
const int   daylightOffset_sec = 3600;

int  iheader = 99999;  // begin serial output by writing header
int  irelauto = 0;  // relay state based on sensor values, 1=on, 0=off
char message[4096];
char relON[12];
char relOFF[12];
char relAUTO[12];
char refMANUAL[12];
char refAUTO[12];
char meta_refresh[48];
char relay_state[8];
unsigned long currentTime, lastChrTime, msecNow, msecInc;
unsigned long nextSerialTime = 0;
unsigned long msecPrev = 0;
char month[12][4];
union { uint32_t store32i; float store32f; char store32c[4]; } store32ifc;
uint32_t bulbsectot = 0;  // time (sec) bulb intensity (UV index) has been above minimum
float uvindexmax = 0;
float uvindexmin = 0;


void setup()
{
   char chrini, chrfin;

   Wire.begin();
   Serial.begin(115200);  // Baud rate for serial output.

   // Initialize relay and sensors.
   if(!relay.begin()) Serial.println("Relay did not initialize.");
   else               Serial.println("Relay initialized.");
```

```
relay.turnRelayOff();
strcpy(relOFF, " selected");
relON[0]   = '\0';
relAUTO[0] = '\0';

if(!bme.begin()) Serial.println("BME680 did not initialize.");
else             Serial.println("BME680 initialized.");
bme.setTemperatureOversampling(BME680_OS_8X);
bme.setHumidityOversampling(BME680_OS_2X);
bme.setPressureOversampling(BME680_OS_4X);
bme.setIIRFilterSize(BME680_FILTER_SIZE_3);
bme.setGasHeater(320, 150);  // 320*C for 150 ms

if(!tvoc_co2.begin()) Serial.println("SGP30 did not initialize.");
else                  Serial.println("SGP30 initialized.");
tvoc_co2.initAirQuality();

if(!uv.begin()) Serial.println("VEML6075 did not initialize.");
else            Serial.println("VEML6075 initialized.");

// Start with manual refresh.
meta_refresh[0] = '\0';
strcpy(refMANUAL, " selected");
refAUTO[0] = '\0';

// Connect to Wi-Fi network with SSID and password.
Serial.print("Connecting to ");
Serial.println(ssid);
WiFi.begin(ssid, pwd);
while (WiFi.status() != WL_CONNECTED)
{
  delay(500);
  Serial.print(".");
}

// Initialize time clock.
configTime(gmtOffset_sec, daylightOffset_sec, ntpServer);
strcpy(month[0], "JAN"); strcpy(month[ 1], "FEB"); strcpy(month[ 2], "MAR");
strcpy(month[3], "APR"); strcpy(month[ 4], "MAY"); strcpy(month[ 5], "JUN");
strcpy(month[6], "JUL"); strcpy(month[ 7], "AUG"); strcpy(month[ 8], "SEP");
strcpy(month[9], "OCT"); strcpy(month[10], "NOV"); strcpy(month[11], "DEC");
```

```
    // Initialize bulb time using value stored in EEPROM if it exists.
    chrini = EEPROM.read(0);
    chrfin = EEPROM.read(5);
    if(chrini == ':'  &&  chrfin == ';')
    {
       store32ifc.store32c[0] = EEPROM.read(1);
       store32ifc.store32c[1] = EEPROM.read(2);
       store32ifc.store32c[2] = EEPROM.read(3);
       store32ifc.store32c[3] = EEPROM.read(4);
       bulbsectot = store32ifc.store32i;
    }

    // Initialize UV index maximum (for determining when bulb should be changed).
    chrini = EEPROM.read(8);
    chrfin = EEPROM.read(13);
    if(chrini == ':'  &&  chrfin == ';')
    {
       store32ifc.store32c[0] = EEPROM.read( 9);
       store32ifc.store32c[1] = EEPROM.read(10);
       store32ifc.store32c[2] = EEPROM.read(11);
       store32ifc.store32c[3] = EEPROM.read(12);
       uvindexmax = store32ifc.store32f;
       uvindexmin = 0.5f * uvindexmax;
    }
    uvindexmin = 0.015625;  // 1/2^6  This needs to be updated.

    // Print local IP address and start web server
    Serial.println("");
    Serial.println("WiFi connected.");
    Serial.print("Local IP address:  ");
    Serial.println(WiFi.localIP());
    server.begin();
}

void loop()
{
    int    i, isetrel, isetcli, isetser, isethed, isetzro, isetron, isetrof, len;
    int    iyear, imonth, imday, ihour, iminute;
    char   chr;
    char   refbutton[256], relay_control[512];
    char   temp[8], datenow[16], timenow[16], monthday[16], thisyear[16];
    float  uva, uvb, uvindex;
```

```
double press, air_resistance, resistanceAQI, humidityAQI, AQI;
struct tm timeinfo;
uint8_t relayStateNow  = 0;
uint8_t relayStatePrev = 0;
uint32_t bulbdays, bulbhours, bulbminutes, bulbhourstot;

// Get readings from sensors.
bme.performReading();
tvoc_co2.measureAirQuality();
if(relay.getState() == 0) strcpy(relay_state, "OFF");
else                      strcpy(relay_state, "ON" );
press   = (double)bme.pressure;
press  /= 1000.0;
uva     = uv.a();
uvb     = uv.b();
uvindex = uv.index();

// Calculate air quality index (AQI) from air resistance and humidity.
// AQI:         0         500
// resistance:  50K       5K        (75% of AQI)
// humidity:    40%    100% or 0%   (25% of AQI)
air_resistance = bme.gas_resistance;

for(i=0; i<9; i++)
{
   delay(10);
   air_resistance += (double)bme.readGas();
}
air_resistance = air_resistance / 10.0; // 0.1 second average
if(air_resistance > 50000) air_resistance = 50000;
if(air_resistance <  5000) air_resistance =  5000;

resistanceAQI = (50000.0 - air_resistance) * (500.0 / 45000.0);

if(bme.humidity > 40.0) humidityAQI = 8.33333 * (bme.humidity - 40.0);
else                    humidityAQI = 12.5 * (40 - bme.humidity);

AQI = (0.75 * resistanceAQI) + (0.25 * humidityAQI);

// Update maximum value of UV index if it has changed.
if(uvindex > uvindexmax)
{
```

```
   uvindexmax = uvindex;
   store32ifc.store32f = uvindexmax;
   EEPROM.write( 8, ':');
   EEPROM.write( 9, store32ifc.store32c[0]);
   EEPROM.write(10, store32ifc.store32c[1]);
   EEPROM.write(11, store32ifc.store32c[2]);
   EEPROM.write(12, store32ifc.store32c[3]);
   EEPROM.write(13, ';');
   uvindexmin = 0.5f * uvindexmax;  // This value may need to be adjusted.
}

// If relay is on, increment and save the time that bulb intensity (UV index) is above minimum.
relayStateNow = relay.getState();
msecNow       = millis();

if(relayStateNow != 0  &&  uvindex > 0.0)
{
   if(relayStatePrev != 0)
   {
      if(uvindex > uvindexmin)
      {
         if(msecNow >= msecPrev) msecInc = msecNow - msecPrev;
         else                    msecInc = msecNow + (0xFFFFFFFF - msecPrev);  // when millis overflows
         bulbsectot += (msecInc / 1000);
         store32ifc.store32i = bulbsectot;
         EEPROM.write(0, ':');
         EEPROM.write(1, store32ifc.store32c[0]);
         EEPROM.write(2, store32ifc.store32c[1]);
         EEPROM.write(3, store32ifc.store32c[2]);
         EEPROM.write(4, store32ifc.store32c[3]);
         EEPROM.write(5, ';');
      }
   }
}
relayStatePrev = relayStateNow;
msecPrev       = msecNow;
bulbdays       = bulbsectot / 86400;
bulbhours      = (bulbsectot - (86400 * bulbdays)) / 3600;
bulbminutes    = (bulbsectot - (86400 * bulbdays) - (3600 * bulbhours)) / 60;
bulbhourstot   = bulbsectot /  3600;

// Get date and time.
```

```
    if(getLocalTime(&timeinfo) != 0)
    {
        iyear   = timeinfo.tm_year + 1900;
        imonth  = timeinfo.tm_mon;
        imday   = timeinfo.tm_mday;
        ihour   = timeinfo.tm_hour;
        iminute = timeinfo.tm_min;
        sprintf(monthday, "%s %02d", month[imonth], imday);
        sprintf(thisyear, "%d", iyear);
        sprintf(datenow,  "%s %02d, %d", month[imonth], imday, iyear);
        sprintf(timenow,  "%0d:%02d", ihour, iminute);
    }
    else
    {
        datenow[0] = '\0';
        timenow[0] = '\0';
    }

    // Write header for sensor readings.
    if(iheader >= header_interval)
    {
        sprintf(message, "%s   C     kPa      %%      ppb     ppm     hrs\n"
                         " %s   Temp  Press    Hum    TVOC     CO2    Bulb   AQI     UVa     UVb   UVidx  Relay\n",
monthday, thisyear);
        Serial.print(message);
        iheader = 0;
    }

    // Write sensor values and time to serial output.
    currentTime = millis();
    if(currentTime >= nextSerialTime)
    {
        sprintf(message, "%s %6.1f %6.1f %6.1f %7d %7d %7d %5.0f %7.1f %7.1f %7.1f   %s\n",
                timenow, bme.temperature, press, bme.humidity,
                tvoc_co2.TVOC, tvoc_co2.CO2, bulbhourstot, AQI, uva, uvb, uvindex, relay_state);
        Serial.print(message);
        nextSerialTime = currentTime + (1000 * serial_interval);
        iheader++;
    }

    // Listen for incoming clients
    WiFiClient client = server.available();
```

```
// If a client is available and connected, read data coming from it.
if(client)
{
   currentTime = millis();
   lastChrTime = currentTime;
   len = 0;

   while(client.connected())
   {
      if(client.available() != 0)  // See if character ready to read
      {
         chr = client.read();
         message[len] = chr;
         len++;
         if(chr == '\n'  &&  message[len-2] == '\n') break;
      }
      currentTime = millis();
      if((currentTime - lastChrTime) > timeout) break;
   }
   message[len] = '\0';

   // Analyze message from client. Look for selections from dropdown menus.
   isetrel = 0;
   isetcli = 0;
   isetser = 0;
   isethed = 0;
   isetzro = 0;
   isetron = 0;
   isetrof = 0;

   for(i=0; i<len; i++)
   {
      if(message[i] == '?')
      {
         if(isetrel == 0  &&  memcmp(&message[i], "?relay=ON"  , 9) == 0)
         {
            relay.turnRelayOn();
            strcpy(relay_state, "ON");
            strcpy(relON, " selected");
            relOFF[0]  = '\0';
            relAUTO[0] = '\0';
            isetrel    = 1;
```

```
    irelauto   = 0;
  }
  if(isetrel == 0  &&  memcmp(&message[i], "?relay=OFF" , 9) == 0)
  {
    relay.turnRelayOff();
    strcpy(relay_state, "OFF");
    strcpy(relOFF, " selected");
    relON[0]   = '\0';
    relAUTO[0] = '\0';
    isetrel    = 1;
    irelauto   = 0;
  }
  if(isetrel == 0  &&  memcmp(&message[i], "?relay=AUTO", 9) == 0)
  {
    strcpy(relAUTO, " selected");
    relON[0]   = '\0';
    relOFF[0]  = '\0';
    isetrel    = 1;
    irelauto   = 1;
  }

  if(isetcli == 0  &&  memcmp(&message[i], "?client_refresh=",  16) == 0)
  {
    memcpy(temp, &message[i+16], 7);
    isetcli = 1;
    temp[7] = '\0';
    client_refresh = atoi(temp);
    if(client_refresh < 3) client_refresh = 3;
  }

  if(isetser == 0  &&  memcmp(&message[i], "?serial_interval=", 16) == 0)
  {
    memcpy(temp, &message[i+17], 7);
    isetser = 1;
    temp[7] = '\0';
    serial_interval = atoi(temp);
    if(serial_interval < 3) serial_interval = 3;
  }

  if(isethed == 0  &&  memcmp(&message[i], "?header_interval=", 16) == 0)
  {
    memcpy(temp, &message[i+17], 7);
```

```
            isethed = 1;
            temp[7] = '\0';
            header_interval = atoi(temp);
            if(header_interval < 2) client_refresh = 2;
        }

        if(isetzro == 0  &&  memcmp(&message[i], "?zero_bulb=", 10) == 0)
        {
            isetzro = 1;
            if(message[i+11]=='Z' && message[i+13]=='R' && message[i+12]=='E' &&
message[i+14]=='O')
            {
                EEPROM.write( 0, ':');
                EEPROM.write( 1, 0x00);
                EEPROM.write( 2, 0x00);
                EEPROM.write( 3, 0x00);
                EEPROM.write( 4, 0x00);
                EEPROM.write( 5, ';');
                EEPROM.write( 8, ':');
                EEPROM.write( 9, 0x00);
                EEPROM.write(10, 0x00);
                EEPROM.write(11, 0x00);
                EEPROM.write(12, 0x00);
                EEPROM.write(13, ';');
                bulbsectot = 0;
                uvindexmax = 0;
                uvindexmin = 0;
            }
        }

        if(isetron == 0  &&  memcmp(&message[i], "?relay_on_tvoc=", 14) == 0)
        {
            memcpy(temp, &message[i+15], 7);
            isetron = 1;
            temp[7] = '\0';
            relay_on_tvoc = (uint16_t)atoi(temp);
            if(relay_on_tvoc < relay_off_tvoc) relay_on_tvoc = relay_off_tvoc;
        }

        if(isetrof == 0  &&  memcmp(&message[i], "?relay_off_tvoc=", 14) == 0)
        {
            memcpy(temp, &message[i+16], 7);
            isetrof = 1;
```

```
                temp[7] = '\0';
                relay_off_tvoc = (uint16_t)atoi(temp);
                if(relay_off_tvoc > relay_on_tvoc) relay_off_tvoc = relay_on_tvoc;
            }
        }
    }

    // Set relay based on sensor readings.
    relay_control[0] = '\0';

    if(irelauto != 0)
    {
        if(tvoc_co2.TVOC > relay_on_tvoc)
        {
            relay.turnRelayOn() ;
            strcpy(relay_state, "ON" );
        }
        else if(tvoc_co2.TVOC < relay_off_tvoc)
        {
            relay.turnRelayOff();
            strcpy(relay_state, "OFF");
        }

        sprintf(relay_control, "<br>"
                        "<form>"
                            "<label for=\"relay_on_tvoc\"><i class=\"fas fa-arrow-up\"></i> Relay on
TVOC:</label>"
                            "<input type=\"text\" id=\"relay_on_tvoc\" name=\"relay_on_tvoc\" size=\"4\"
value=\"%d\"><br>"
                        "</form>"
                        "<br>"
                        "<form>"
                            "<label for=\"relay_off_tvoc\"><i class=\"fas fa-arrow-down\"></i> Relay off
TVOC:</label>"
                            "<input type=\"text\" id=\"relay_off_tvoc\" name=\"relay_off_tvoc\" size=\"4\"
value=\"%d\"><br>"
                        "</form>", relay_on_tvoc, relay_off_tvoc);
    }

    // Show refresh button if client refresh is greater than 10 seconds.
    if(client_refresh < 10)
    {
        refbutton[0] = '\0';
```

```
}
else
{
   strcpy(refbutton, "<br><form>"
                     "<button style=\"background-color:GreenYellow\" type=\"submit\" "
                            "name=\"manref\" value=\"REF\">REFRESH</button>"
                     "</form>");    // returned to server:  ?manref=REF
}

// Send web page to client.
sprintf(message, "HTTP/1.1 200 OK\n"
                 "Server: TKE/0.0\n"
                 "Accept-Ranges: bytes\n"
                 "Connection: close\n"
                 "Content-Type: text/html\n"
                 "\n"
                 "<!DOCTYPE html>"
                 "<html style=\"font-family:verdana\">"
                 "<meta name=\"viewport\" content=\"initial-scale=1\">"
                 "<title>New-EIR UV-C App</title>"
                 "<head>"
                 "<meta name=\"viewport\" content=\"width=device-width, initial-scale=1\">"
                 "<link rel=\"stylesheet\" href=\"https://use.fontawesome.com/releases/v5.7.2/css/all.css\"
integrity=\"sha384-fnmOCqbTlWIlj8LyTjo7mOUStjsKC4pOpQbqyi7RrhN7udi9RwhKkMHpvLbHG9Sr\"
crossorigin=\"anonymous\">"
                 "<link rel=\"icon\" href=\"data:,\">"
                 "<style>"
                   "html {font-family: Arial; display: inline-block; text-align: center;}"
                   "p {  font-size: 1.2rem;}"
                   "body {  margin: 0;}"
                   ".topnav { overflow: hidden; background-color: #8800FF; color: white; font-size: 1.7rem;
}"
                   ".content { padding: 20px; }"
                   ".card { background-color: white; box-shadow: 2px 2px 12px 1px rgba(140,140,140,.5); }"
                   ".cards { max-width: 700px; margin: 0 auto; display: grid; grid-gap: 2rem; grid-template-
columns: repeat(auto-fit, minmax(300px, 1fr)); }"
                   ".reading { font-size: 2.8rem; }"
                   ".card.temperature { color: #0e7c7b; }"
                   ".card.humidity { color: #17bebb; }"
                   ".card.pressure { color: #4B1D3F; }"
                   ".card.gas { color: #0044ff; }"
                 "</style>"
                 "</head>"
```

```
                    "<meta http-equiv=\"refresh\" content=\"%d\">"
                    "<br><br>"
                    "<body>"
                    "<div class=\"topnav\">"
                    "<h3>New-EIR UV-C App</h3>"
                    "</div>"
                    "<div class=\"content\">"
                    "<div class=\"cards\">"
                    "<div class=\"card temperature\">"
                      "<h1>30-DAY Report<br>Welcome to:</h1>"
                      "<h2>Stinger's Cafe</h2>"
                      "<h3>6000 J St. Sacramento, CA <br> 95819-6055</h3>"
                      "<h4>This Business has air sanitized and monitored by <br> 'New-EIR Germicidal UV-C'
<br> for the safety, health and comfort of your customers. Ozone Free!</h4>"
                      "<p style=\"font-size:10px\">Scan this QRcode to goto our webpage: <i class=\"fas fa-
external-link-alt\"></i></p> <address><a href=\"https://sites.google.com/view/new-
eiriaq\">sites.google.com/view/new-eiriaq</a></address><br>"
                      "<img src=\"https://docs.google.com/drawings/d/e/2PACX-1vTa5l5IPNuLwZHn7b-
yIDdKVXMi40wL0mT7YrQBGJmv7PBa23s-
kqaKXxT_WkLeiL65R8BQA4RPw0kq/pub?w=240&amp;h=295\"><br>"
                      "<p style=\"font-size:10px\">Keep this report on display for your customers' assurance of
safety, health and comfort. Replace every week.</p><br>"
                    "</div>"
                    "<div class=\"card pressure\">"
                      "<h1>Readings</h1>"
                        "<i class=\"fas fa-calendar-day\"></i> %s  %s<br>"
                        "<i class=\"fas fa-thermometer-half\"></i> Temperature (20-26 &deg;C) = %7.2f<br>"
                        "<i class=\"fas fa-tachometer-alt\"></i> Pressure (95-101 kPa) = %7.2f<br>"
                        "<i class=\"fas fa-tint\"></i> Humidity (30-45 &percnt;)  = %7.1f<br>"
                        "<i class=\"fas fa-dizzy\"></i> TVOC (0-500 ppb) = %d<br>"
                        "<i class=\"fas fa-skull\"></i> CO2 (400-1000 ppm)  = %d<br>"
                        "<i class=\"fas fa-air-freshener\"></i> AQI (< 50)= %7.0f<br>"
                        "<i class=\"fas fa-sun\"></i> UVindex (>51 &micro;W/cm&sup2) = %7.1f<br>"
                        "<iframe width=\"300\" height=\"260\" seamless frameborder=\"0\" scrolling=\"no\"
src=\"https://docs.google.com/spreadsheets/d/e/2PACX-
1vR9FhxYm7vf5wwHYgRqjywVEX_XNbWSjp_XNNh6TO3L29nXAS0WXhmC-
SytIRtHyu1uat2mJoaybN9d/pubchart?oid=2126194809&amp;format=interactive\"></iframe>"
                        "<iframe width=\"300\" height=\"260\" seamless frameborder=\"0\" scrolling=\"no\"
src=\"https://docs.google.com/spreadsheets/d/e/2PACX-
1vR9FhxYm7vf5wwHYgRqjywVEX_XNbWSjp_XNNh6TO3L29nXAS0WXhmC-
SytIRtHyu1uat2mJoaybN9d/pubchart?oid=350343&amp;format=interactive\"></iframe>"
                      "<form>"
                    "</div>"
                    "</div><br><br><br>"
```

```
        "<i class=\"fas fa-sun\"></i> UVa          = %7.1f<br>"
        "<i class=\"fas fa-sun\"></i> UVb          = %7.1f<br>"
      "<i class=\"fas fa-toggle-on\"></i> Relay  = %s<br>"
      "<i class=\"far fa-lightbulb\"></i> bulb on: %d days %d hours %d minutes<br>"
      "<div><br>"
        "<label for=\"relay\"><i class=\"fas fa-toggle-on\"></i> Relay:  </label>"
        "<select id=\"relay\" name=\"relay\" onchange=\"this.form.submit()\">"
          "<option%s>ON</option>"
          "<option%s>OFF</option>"
          "<option%s>AUTO</option>"
        "</select>"
      "</form>"
      "<br><br>"
      "<form>"
        "<label for=\"client_refresh\"><i class=\"fas fa-clock\"></i> Seconds between WiFi
refresh:</label>"
        "<input type=\"text\" id=\"client_refresh\" name=\"client_refresh\" size=\"4\"
value=\"%d\"><br>"
      "</form>"
      "<br>"
      "<form>"
        "<label for=\"serial_interval\"><i class=\"fas fa-hourglass-half\"></i> Seconds between
serial output:</label>"
        "<input type=\"text\" id=\"serial_interval\" name=\"serial_interval\" size=\"4\"
value=\"%d\"><br>"
      "</form>"
      "<br>"
      "<form>"
        "<label for=\"header_interval\"><i class=\"fas fa-list\"></i> Lines between serial output
headers:</label>"
        "<input type=\"text\" id=\"header_interval\" name=\"header_interval\" size=\"4\"
value=\"%d\"><br>"
      "</form>"
      "<br>"
      "<form>"
        "<label for=\"zero_bulb\"><i class=\"fas fa-question\"></i> Password to zero bulb
time:</label>"
        "<input type=\"text\" id=\"zero_bulb\" name=\"zero_bulb\" size=\"4\" value=\"\">"
      "</form>"
      "<br>"
      "%s"
      "%s"
      "</div><br>"
```

```
                            "<button onclick=\"window.print()\">Print 30-Day Report</button><br><br>"
                          "</div>"
                          "</div>"
                          "</body>"
                          "</html>", client_refresh, datenow, timenow,
                                    bme.temperature, press, bme.humidity,
                                    tvoc_co2.TVOC, tvoc_co2.CO2, AQI, uvindex, uva, uvb,
                                    relay_state, bulbdays, bulbhours, bulbminutes,
                                    relON, relOFF, relAUTO,
                                    client_refresh, serial_interval, header_interval,
                                    relay_control, refbutton);

        client.println(message);

        // Close connection to the client
        client.stop();
    }
}
```

Table XII-2 Program Code [30].

APPENDIX D.
Mechanical Aspects

	Dosage												
Current	Length	Electrical Input	GUV-C Output	Efficiency	Cylinerical Area	Dosage	Distance						
(mA)	(cm)	(Watts)	(Watts)	Input / Output	2(pi*r^2)+pi*r*l	(microW @1m)	0.001	0.01	0.02	0.03	0.04	0.05	0.06
425	12.25	6	1.7	0.28333	70528.7551	24.10364	1.8E+07	180000	45000	20000	11250	7200	5000
425	14.7	8	2.5	0.3125	72068.1355	34.68939	2.4E+07	240000	60000	26666.7	15000	9600	6666.67
425	17.15	9	2.4	0.26667	73607.5159	32.60537	2.7E+07	270000	67500	30000	16875	10800	7500
425	20.43	10	2.3	0.23	75668.4007	30.39578	3E+07	300000	75000	33333.3	18750	12000	8333.33
425	27.69	14	4.0	0.28571	80229.9932	49.85667	4.2E+07	420000	105000	46666.7	26250	16800	11666.7
425	29.65	15	4.9	0.32667	81461.4975	60.15112	4.5E+07	450000	112500	50000	28125	18000	12500
425	31.85	16	4.9	0.30625	82843.7983	59.14746	4.8E+07	480000	120000	53333.3	30000	19200	13333.3
425	34.45	17	5.2	0.30588	84477.4265	61.55491	5.1E+07	510000	127500	56666.7	31875	20400	14166.7
425	42.04	20	6.4	0.32	89246.3641	71.7116	6E+07	600000	150000	66666.7	37500	24000	16666.7
425	43.41	21	6.6	0.31429	90107.1605	73.24612	6.3E+07	630000	157500	70000	39375	25200	17500
425	44.64	22	6.9	0.31364	90879.9923	75.9243	6.6E+07	660000	165000	73333.3	41250	26400	18333.3

Table D-1 UV Dosage [30]

APPENDIX E.
Vendor Contacts

1000Bulbs.com	2140 Merritt Dr, Garland, TX 75041	800-624-4488
ballastshop.com	3558 Lee Rd, Cleveland, OH 44120	
buyultraviolet.com	375 Marcus Blvd, Hauppauge, NY 11788	631-494-7331
johnsoncontrols.com	103 Woodmere Rd, Folsom, CA 95630	916-294-8800
mouser.com	1000 North Main St, Mansfield, TX 76063	800-346-6873
sparkfun.com	6333 Dry Creek Pkwy, Niwot, CO 80503	303-284-0979
Performance Heating & Air	5011 Golden Foothill Pkwy Ste 5B, El Dorado Hills, CA 95762	

Table E-1 Vendor Contact list [30]

APPENDIX F.

Aaron Costello’s Resume

KNOWLEDGE AND SKILLS

SOLIDWORKS, C++, PSpice, Multisim

EDUCATION

Electrical and Electronic Engineering, BS 08/2018 **-** Present
California State University Sacramento GPA: 2.84
Relevant Coursework

Associate of Arts: Mathematics 05/2017
San Diego Mesa College - San Diego CA GPA: 3.1

PROFESSIONAL or WORK EXPERIENCE

Assistant Varsity Boys Basketball Coach 09/2013 - 02/2015
Livermore High School, Livermore, CA

- Developed specific drills tailored to individuals and groups of 2 to 10 players.
- Teamed with superiors to determine best way to inspire exceptional individual performance.
- Helped lead team to second playoff appearance in 15 years.

Barista 07/2018 - 01/2020
Starbucks, Sacramento, CA

- Effectively communicated with up to 7 team members at once to control line and provide efficient, quality service.
- Maintained clean, organized environment especially in times of high traffic.
- Created lasting customer connections by being personable.

Clements, G. Clements' Resume

KNOWLEDGE AND SKILLS

ASHRAE, HVAC-R, control systems, circuit analysis, Blueprints, Matlab, Microsoft Office, CADD, PLCs, ADS, Verilog, manufacturing, janitorial, construction, apartment repairs.

EDUCATION

Electrical and Electronic Engineering, BS Present
California State University Sacramento GPA 3.326
Circuit Analysis, Verilog, ADS, MatLab, C# programming, Electronics

Applied Engineering, Operations AAS 01/12-05/15
College of Southern Nevada GPA 3.940, 62 credits
CADD, PLCs, Microsoft Office, Machine repair, Blueprints

EPA Section 608 Universal & OHSA10 01/10-07/10
Advanced Training Institute GPA 3.500, 455 Hours
Electrical, Mechanical, Heaters, Air Conditioners, Refrigeration, OSHA

PROFESSIONAL or WORK EXPERIENCE

HVAC Technician 5/17-Present
Performance Heating and Air, El Dorado Hills CA
HVAC-R maintenance and repairs, troubleshooting electrical

Facility Operations Engineer 10/15-10/16
VA NW PC Clinic, Las Vegas Nv.
Routine maintenance on Chilled Water Systems, VFD, and Johnson Controls' Metasys® BAS ordering supplies, contacting venders

Home Automation Tech. 5/15-09/15
Northstar Alarm, Raleigh NC
Home Automation install, track inventory, customer relations

HVAC Technician 5/14-8/14
Stovepipe Wells Village, Death Valley NP, CA.
Troubleshooting and routine maintenance on walk-in coolers and freezers, blast chillers, ice machines, 2-stage heat pumps, window units, restaurant kitchen equipment

Service Manager 08/11-11/13
Rancho Destino Apartments, Las Vegas NV.
HVAC, appliance, plumbing and lighting repairs, ordering supplies, contacting venters

HVAC Maintenance Tech 08/10-08/11
Alta Montecito Apartments, Las Vegas NV.
HVAC, appliance, plumbing and lighting repairs, grounds keeping, painting

Alexander Garcia's Resume

KNOWLEDGE AND SKILLS

Exceptional Customer service, Management, Math based education background, Proficient in Microsoft Suit Software, Bilingual: English and Spanish

EDUCATION

Electrical and Electronic Engineering, BS Exp. Grad. May 2021
California State University Sacramento GPA 2.92
Electronics w/ Lab, Intro to Microprocessors, Signals and Systems

Associate of Science: Mathematics 05/2017
Chabot College - Hayward CA GPA: 3.0

PROFESSIONAL or WORK EXPERIENCE

Lead driver 2019-08/2020
Dominos Pizza Sacramento, CA
Made sure that every costumer is satisfied while maintained clean environment and followed Covid regulations

Logistics Manager 2017-09/2018
Amazon, Newark, CA
Managed logistics of multiple shipments and deliveries within extreme time constraints

Server Position 2014-05/2017
El Torito Restaurant, San Lorenzo, CA
Computed and reported daily transactions using POS system and safe money handling practices

Crew Manager 2007-08/2018
Garcia's Irrigations, San Lorenzo, CA
Managed all landscape crews in installation and maintenance of Landscape projects from simple tree removal and installation to complete complex landscape design and installation of all trees, shrubs, lawns, mulch and flowering landscape installation

Maksim Repko's Resume

KNOWLEDGE AND SKILLS

Adept at coding in Java, VHDL, Verilog, Assembly Language, and Python. Adept at learn coding languages quickly and efficiently, as well as learning how to work in new IDE's and other work environments. Experience working in laboratory environments with a focus on gathering, verifying, and analyzing data. Experience in robotics, as well as managing and coordinating a team in order to make a competitively viable robot. Experience in project leadership and management. Fluent Russian and English speaker.

EDUCATION

Computer Engineering, BS Exp. Grad. May 2021
California State University Sacramento GPA 3.448
Relevant Coursework
CpE 142: Adv. Computer Organization, 166: Advanced Logic Design, CpE 186: Computer Hardware Design, EEE 108: Electronics I, EEE 108L: Electronics I Lab

REFERENCES

Dmitriy Repko (xxx -xxx-xxxx)
Senior Quality Assurance Engineer @ Malwarebytes

Mamoun Abu-Samaha (xxx-xxx-xxxx)
CTO/ Professor & Director of Cybersecurity @ International Technological University

Richard Torres' Resume

KNOWLEDGE AND SKILLS

SolidWorks design, Electronics repair, Exceptional Customer service, Management, Team communication, Project leadership, Fluent Spanish speaker

EDUCATION

EEE, BS — Present
California State University Sacramento — GPA 3.064
Engineering Graphics and CADD, Electronics w/ Lab, Intro to Microprocessors, Signals and Systems

PROFESSIONAL or WORK EXPERIENCE

Equipment technician — Sept 2017 – Aug 2019
Sight and Sound — Sacramento, CA
Load, Unload, and connect audio and video equipment
Troubleshoot damaged equipment and perform the repairs

Equipment technician — Aug 2018 – Aug 2019
34orty — Sacramento, CA
Load, Unload, and connect audio and video equipment
her roles in other departments when requested

APPENDIX G.

Table G1

Work Breakdown Structure

Task	Description	Team Member	Cost	Start Date	Duration	Due date
1.Indoor features						
1.1 Hardware						
1.1.1 UV Bulb	The main sources of air sterilization. The bulb will be placed after the air filter and within 1 meter of the Evap. Coil or heat exchanger to provide >50$\mu W/cm^2$. The UV-C radiation will kill or inactivate any microbes on the heat exchanger and in the air. Research and purchase the bulb	Clements, G. Alex Garcia	$6-40			10/21/20
1.1.1.1 Fixture	With UV-C bulb affixed between heat exchanger and filter the UV-C bulb will be kept free of dust and sterilize any microbes not caught be filter <0.3 µm. The bulb will sit in a small metallic holder that will be cut through the HVAC frame and sealed.	Aaron Costello	$4			11/7/2020
1.1.2.3 Ballast	Regulates the voltage and current to UV-C lamp during start-up and use. Input: 24Vdc Power:10-20W	Alex Garcia	$30-140			10/25/20
1.1.4 Sensor	All i2c connections must be within 2 meters or shielded to prevent inductive charge damaging circuits.	Clements, G.				10/25/20
1.1.4.1 UV Sensor	The UV Light Sensor measures ultraviolet output intensity	Clements, G.	$12			10/29/20

	within a distance of 1 meter.					
1.1.4.2 IAQ Sensor	Provides information on the quality of the air in your room or house by monitoring the total volatile organic compounds in the air moving through the HVAC system.	Clements, G.	$20			10/20/20
1.1.4.3 UV-s Fixture	UV Sensor will be placed within 1 meter of the UV-C light in order to be able to prove correct dosage. The UV sensor will report readings to the board via i2c.	Clements, G.				10/20/20
1.1.4.4 IAQ –s Fixture	Placed inside HVAC air flow to get reading of the air quality being distributed throughout the building. IAQ will be connected to…	Clements, G.				03/01/21
1.1.5 Wiring						
1.1.5.1 Casing	Optimize bulb and sensor placement to fit inside multiple systems. Purchasing a length of cover suitable for outdoor use to prevent normal outdoor wear and tear. Metallic wire covering	Richard Torres				11/21/20
1.1.5.2 Wires	Wiring to PV solar array 12-14AWG at a max length 26ft. Wiring to ballast and lamp 18AWG.	Richard Torres				11/7/20
1.1.5.3 Safety	Wiring needs over current protection and safety switches to ensure the	Aaron Costello				11/10/20

	equipment is only used when properly installed and enclosed.					
2 Outdoor features			$19			
2.1 Hardware						
2.1.1 Board	Obtain SparkFun ESP32 Thing Plus, review its specs and be able to troubleshoot technical issues that come up.	Alex Garcia	$21			10/21/20
2.1.2 Outdoor air quality Sensor	Obtain all sensors listed above and connect to board. IAQ, TVOC.	Clements, G.	$19			03/30/20
2.1.3 Battery		Alex Garcia	$18			03/30/21
2.1.3.1 Battery Charging	Battery will be charged up by the solar panels. Test the panels' ability to charge the battery, and charge time.	Alex Garcia				03/30/21
2.1.3.2 Battery Powering Device	The battery will be connected to and will power the UV-C lamp.	Alex Garcia				03/30/21
2.1.4 Solar Panels	Will be placed in an area where sun light hits the best. Will be a source of power that will charge up the battery and proved power to the system. Purchase the panels and mark measurements in order to make frame for holding the panels.	Richard Torres				03/30/21
2.1.5 Wiring	Wires will need to extend from the panels to the battery, then connect the battery to the board. a certain length will	Richard Torres				02/3/21

	need to be measures and accounted for.					
2.1.6 Frame	Solar panel frame and holder for the batteries. Should shield the batter from the elements and have the panels facing upward. The sensors may be placed on the frame and close to the board.	Richard Torres				02/3/21
2.2 Software						
2.2.1 Relay	STDP relay controlled by microcontroller to turn on light.	Alex Garcia	$12			10/20/20
2.2.2 Sensor data	The sensor data that will be collected and transmitted will be collected and stored in the I2C format.	Aaron Costello				11/15/20
2.2.2.1 IAQ	Indoor air sensors will be able to communicate readings with the board and app.	Aaron Costello				11/15/20
2.2.3 Light Control	User will have the option to disable the light through the app. Intensity will be constant.	Aaron Costello				11/15/20
2.2.4 App Communication	The board will communicate with the mobile application and transmit the data via wi-fi	Aaron Costello				11/15/20
3 User App						
3.1 Basic App	Create a basic app that will serve as a template for the fuller, complete app.	Maksim Repko	$0			10/22/20
3.2 Full App	Finish the basic app with all the required features and displays of the data.	Maksim Repko	$0			11/23/20

3.3 Data Display	Display the data received from the board	Maksim Repko	$0			11/23/20
3.3.1 Formatting Style	The data will be displayed as a numerical value, unit, and indicator for the danger level	Maksim Repko	$0			11/23/20
3.3.2 Home Screen Display Menu	Display a button for the user that will allow them to turn board on and off, followed by a data menu that will allow the user to choose what sensor reading they want to see.	Maksim Repko	$0			11/23/20
3.4 Communication	Communicate with the board via wi-fi in order to facilitate data transfer	Maksim Repko	$0			11/23/20
3.5 Preferences Menu	Gives the user a settings page to allow them to modify it lightly	Maksim Repko	$0			12/10/20
3.5.1 Unit Metric	Allows the user to decide between Fahrenheit or Celsius	Maksim Repko	$0			12/10/20
3.5.2 Language Choice	Allows the user to decide on what language they would want the app to be in from a choice of a set amount of the most relevant languages	Maksim Repko	$0			12/10/20
4. Course Assignments						
4.1 Assignment 4 Project Timeline	Prepare a written schedule of tasks and activities for your team's project through May 2021.	Richard Torres Maksim Repko Aaron Costello				11/02/20
4.1.1	Create Grant chart	Clements, G. Alex Garcia				
4.1.1.1	Group tasks into logical family.	Clements, G.				

4.1.1.2	Couple the tasks with the WBS and assign a team member to each task.	Richard Torres Aaron Costello				
4.1.2	Create PERT diagram	Clements, G. Alex Garcia				
4.2 Assignment 5 Risk Assessment	Complete a written risk assessment of your team's project over the entire two semesters.	Clements, G.				11/09/20
4.2.1	Identify the project's critical path and potential events and risks.	Clements, G.				11/09/20
4.2.2	Prepare risk assessment chart for most significant risks.	Alex Garcia				12/07/20
4.3 Assignment 6 Project Technical Evaluation	Demonstrate prototype's feature set to the required measurable metrics with a pre-recorded video.	Richard Torres				12/07/20
4.3.1	Organize technical details of prototype to present.	Clements, G.				11/09/20
4.3.2	Record demonstration which includes all hardware and software features	Alex Garcia				12/07/20
4.4 Assignment 7 Laboratory Prototype Presentation	Present laboratory prototype in the scheduled Senior Design Showcase.	Richard Torres				12/11/20
4.4.1	Create large scale softcopy poster to introduce the project to an audience.	Aaron Costello				12/02/20
Assignment 8 - Team Bulletin Board	Design Board for project info. https://mysacstate-my.sharepoint.com/:p:/g/personal/sac21544_csus_edu/Efp9onRNUPRJkcXIGkMU	Aaron Costello		25-Jan-21	1	1-Feb-21

	7B4BYQq65tD29ZG2sE8Eb7Tw7g?e=YmEquC					
Assignment 9 - Revised Problem Statement	Review and clean up problem statement section of report so as to be up so par with grading rubric	Alex Garcia		25-Jan-21	1	1-Feb-21
Assignment 10 - Device Test Plan Report	Create a test plan, add to report, establish testing timeline, assign testing tasks to members	Alex Garcia & Maksim Repko		25-Jan-21	2	8-Feb-21
Assignment 11 - Market Review	Research competitors in the market, prepare presentation as a sell for the design to a company.	Alex Garcia & Richard Torres		8-Feb-21	3	1-Mar-21
Assignment 12 - Feature Report	Reassess features of the design and present them, this section is a revision of the unique design features, changed through research and testing issues, making for different measurable metrics	Aaron Costello & Clements, G.		1-Mar-21	1	8-Mar-21
Assignment 13 - Mid-term Progress Review	full demonstration of all features to the measurable metrics of your project	Clements, G. & Richard Torres		15-Mar-21	3	5-Apr-21
Assignment 14 - Test Results Report	Following the device test plan present results of the tests, issues problems, changes, timeline, etc.	Maksim Repko		29-Mar-21	1	5-Apr-21
Test Results Report		Maksim Repko		15-Mar-21	3	5-Apr-21
Assignment 15 - Deployable Prototype	Your project will be complete and fully meet the feature set to the design idea contract measurable metrics.	Richard Torres & Aaron Costello		5-Apr-21	3	26-Apr-21

Assignment 16 - Final Documentation Report	Final report is set for publication, maintain and review all sections and have it up to grading rubric and personal & professional standards.	Clements, G. & Richard Torres		12-Apr-21	3	3-May-21

Table G-1 Work Structure Breakdown [42]

APPENDIX H.

PERT Chart

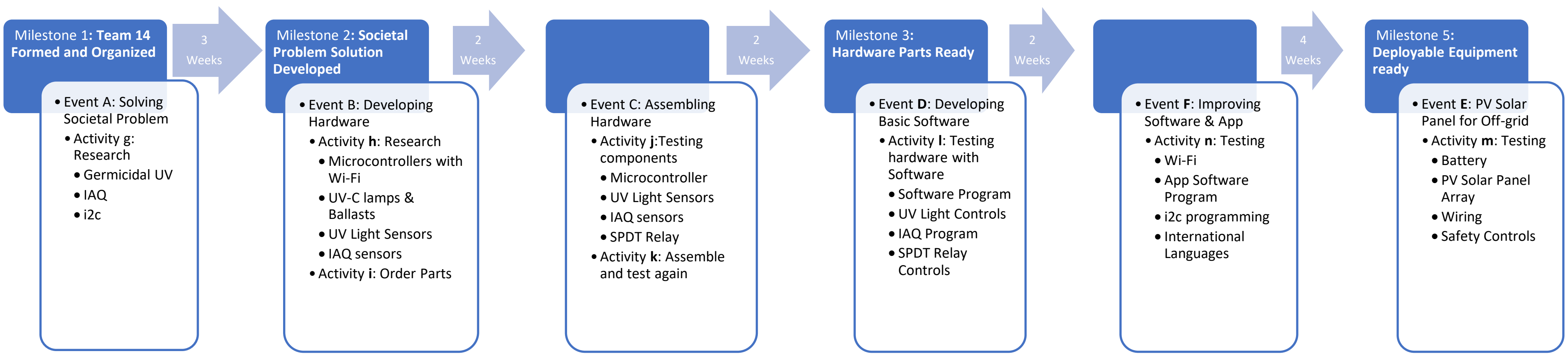


Figure H-1 PERT Chart [43]

Timeline

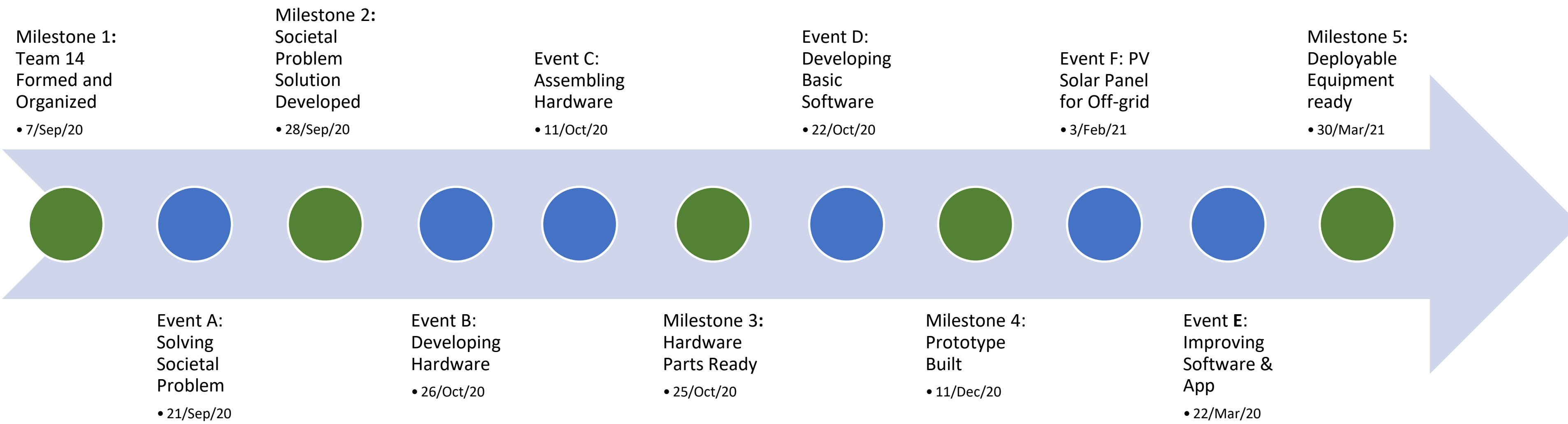


Figure H-2 Timeline [43]

APPENDIX I.

ASHRAE 62.1 Tables

TABLE B-1 Comparison of Regulations and Guidelines Pertinent to Indoor Environments[a]
(The user of any value in this table should take into account the purpose for which it was adopted and the means by which it was developed.)

	Enforceable and/or Regulatory Levels			Nonenforced Guidelines and Reference Levels			
	NAAQS/EPA (Ref. B-4)	OSHA (Ref. B-5)	MAK (Ref. B-2)	Canadian (Ref. B-8)	WHO/Europe (Ref. B-11)	NIOSH (Ref. B-13)	ACGIH (Ref. B-1)
Carbon dioxide		5000 ppm	5000 ppm 10,000 ppm [1 h]	3500 ppm [L]		5000 ppm 30,000 ppm [15 min]	5000 ppm 30,000 ppm [15 min]
Carbon monoxide[c]	9 ppm[g] 35 ppm [1 h][g]	50 ppm	30 ppm 60 ppm [30 min]	11 ppm [8 h] 25 ppm [1 h]	90 ppm [15 min] 50 ppm [30 min] 25 ppm [1 h] 10 ppm [8 h]	35 ppm 200 ppm [C]	25 ppm
Formaldehyde[h]		0.75 ppm 2 ppm [15 min]	0.3 ppm 1 ppm[i]	0.1 ppm [L] 0.05 ppm [L][b]	0.1 mg/m^3 (0.081 ppm) [30 min][p]	0.016 ppm 0.1 ppm [15 min]	0.3 ppm [C]
Lead	1.5 µg/m^3 [3 months]	0.05 mg/m^3	0.1 mg/m3 1 mg/m^3 [30 min]	Minimize exposure	0.5 µg/m^3 [1 yr]	0.050 mg/m^3	0.05 mg/m^3
Nitrogen dioxide	0.05 ppm [1 yr]	5 ppm [C]	5 ppm 10 ppm [5 min]	0.05 ppm 0.25 ppm [1 h]	0.1 ppm[1 h] 0.02 ppm [1 yr]	1 ppm [15 min]	3 ppm 5 ppm [15 min]
Ozone	0.12 ppm [1 h][g] 0.08 ppm	0.1 ppm	j	0.12 ppm [1 h]	0.064 ppm (120 µg/m^3) [8 h]	0.1 ppm [C]	0.05 ppm[k] 0.08 ppm[l] 0.1 ppm[m] 0.2 ppm[n]
Particles[e] <2.5 µm MMAD[d]	15 µg/m^3[1 yr][o] 35 µg/m^3 [24 h][o]	5 mg/m^3	1.5 mg/m^3 for <4 µm	0.1 mg/m^3 [1 h] 0.040 mg/m^3 [L]			3 mg/m^3 [C]
Particles[e] <10 µm MMAD[d]	150 µg/m^3 [24 h][o]		4 mg/m^3				10 mg/m^3 [C]
Radon				800 Bq/m^3 [1 yr]			
Sulfur dioxide	0.03 ppm [1 yr] 0.14 ppm [24 h][g]	5 ppm	0.5 ppm 1 ppm[i]	0.38 ppm [5 min] 0.019 ppm	0.048 ppm [24 h] 0.012 ppm [1 yr]	2 ppm 5 ppm [15 min]	2 ppm 5 ppm [15 min]
Total Particles[e]		15 mg/m^3					

a. Numbers in brackets [ ] refer to either a ceiling or to averaging times of less than or greater than eight hours (min = minutes; h = hours; y = year; C = ceiling, L = long-term). Where no time is specified, the averaging time is eight hours.
b. Target level is 0.05 ppm because of its potential carcinogenic effects. Total aldehydes limited to 1 ppm. Although the epidemiological studies conducted to date provide little convincing evidence that formaldehyde is carcinogenic in human populations, because of this potential, indoor levels should be reduced as much as possible.
c. As one example regarding the use of values in this table, readers should consider the applicability of carbon monoxide concentrations. The concentrations considered acceptable for nonindustrial, as opposed to industrial, exposure are substantially lower. These lower concentrations (in other words, the ambient air quality standards, which are required to consider populations at highest risk) are set to protect the most sensitive subpopulation, individuals with pre-existing heart conditions.
d. MMAD = mass median aerodynamic diameter in microns (micrometers). Less than 3.0 µm is considered respirable; less than 10 µm is considered inhalable.
e. Nuisance particles not otherwise classified (PNOC), not known to contain significant amounts of asbestos, lead, crystalline silica, known carcinogens, or other particles known to cause significant adverse health effects.
f. See Table B-2 for the U.S. EPA guideline.
g. Not to be exceeded more than once per year
h. The U.S. Department of Housing and Urban Development adopted regulations concerning formaldehyde emissions from plywood and particleboard intended to limit the airborne concentration of formaldehyde in manufactured homes to 0.4 ppm. (24 CFR Part 3280, HUD Manufactured Home Construction and Safety Standards). In addition, California Air Resources Board Regulation §93120, entitled "Airborne Toxic Control Measure to Reduce Formaldehyde Emissions from Composite Wood Products" has specific chamber-based requirements for composite wood products sold in California.[B-47]
i. Never to be exceeded
j. Carcinogen, no maximum values established
k. TLV® for heavy work
l. TLV® for moderate work
m. TLV® for light work
n. TLV® for heavy, moderate, or light workloads (less than or equal to two hours)
o. 62FR38652 - 38760, July 16, 1997
p. Epidemiological studies suggest a causal relationship between exposure to formaldehyde and nasopharyngeal cancer, although the conclusion is tempered by the small numbers of observed and expected cases. There are also epidemiological observations of an association between relatively high occupational exposures to formaldehyde and sinonasal cancer.

Guide for Using TABLE B-2

The substances listed in Table B-2 are common air contaminants of concern in nonindustrial environments. The target concentrations that have been set or proposed by various national or international organizations concerned with health and comfort effects of outdoor and indoor air are listed for reference only. The table is not inclusive of all contaminants in indoor air, and achieving the target indoor concentrations for all of the listed substances does not ensure freedom from sensory irritation or from all adverse health effects for all occupants. In addition to indoor contaminant levels, the acceptability of indoor air also involves thermal conditions, indoor moisture levels as they impact microbial growth, and other indoor environmental factors. ASHRAE is not selecting or recommending default concentrations.

Health or comfort effects and exposure periods that are the basis for the guideline levels are listed in the "comments" column. For design, the goal should be to meet the guideline levels continuously during occupancy because people spend the great majority of their time indoors.

Users of this table should recognize that unlisted noxious contaminants can also cause unacceptable IAQ with regard to comfort (sensory irritation), odors, and health. When such contaminants are known or might reasonably be expected to be present, selection of an acceptable concentration and exposure may require reference to other guidelines or a review and evaluation of relevant toxicological and epidemiological literature. (Table B-2 summarizes some of this literature.)

TABLE B-2 Concentration of Interest for Selected Contaminants

(Note: References numbers that are followed by [c] and [m] list the concentrations of interest [c] and measurement methods [m].)

TABLE 2.3.1 (Note: The user of any value in this table should take into account the purpose for which it was adopted and the means by which it was developed.)

Contaminant	Sources	Concentrations of Interest	Comments	References
Carbon Monoxide (CO)	Leaking vented combustion appliances Unvented combustion appliances Parking garages Outdoor air	9 ppm (8 h)	Based on effects on persons with coronary artery disease, average exposure for eight hours. Sustained indoor concentrations exceeding outdoor concentrations may merit further investigation. Many carbon monoxide measuring instruments have limited accuracy at low levels. Sources—burning of gasoline, natural gas, coal, oil, etc. (Note: CO is unlikely to be the only contaminant of concern in parking garages or other spaces where vehicles operate.) Health effects—reduces ability of blood to bring oxygen to body cells and tissues; cells and tissues need oxygen to work. Carbon monoxide may be particularly hazardous to people who have heart or circulatory problems and people who have damaged lungs or breathing passages.	B-4 [c] B-9 [m]
Formaldehyde (HCHO)	Pressed-wood products Furniture and furnishings	0.1 mg/m³ (0.081 ppm) (30 min)	Based on irritation of sensitive people, 30-minute exposure (WHO)	B-11 [c] B-9, 26 [m]
		27 ppb (8 h)	Established as a never-to-exceed guideline to avoid irritant effects in sensitive individuals. Does not protect against formaldehyde's potential carcinogenicity (California Air Resources Board).	B-16
		45 ppb (55 μg/m³) (1 h) 7.3 ppb (9 μg/m³) (8 h)	Acute and 8-hour noncancer Reference Exposure Levels (RELs) developed based on current scientific database (Cal-EPA, OEHHA).	B-36
			Health effects—Acute and chronic inhalation exposure to formaldehyde in humans can result in eye, nose, and throat irritation, respiratory symptoms, exacerbation of asthma, and sensitization. Human studies have reported an association between formaldehyde exposure and lung and nasopharyngeal cancer. In 2004, the International Agency for Research on Cancer (IARC) concluded that "*formaldehyde is carcinogenic to humans (Group 1)*, on the basis of *sufficient evidence* in humans and *sufficient evidence* in experimental animals."	B-19, 20, 36, 40
		16 ppb	FEMA Procurement Specification for Mobile Homes	B-48

[a] The US EPA has promulgated a guideline value of 4 pCi/L indoor concentration. This is not a regulatory value but an action level where mitigation is recommended if the value is exceeded in long-term tests.

Conversion Factors[B-17]

Parts per million and mass per unit volume:

Measurements of indoor airborne concentrations of substances are generally converted to standard conditions of 77°F (25°C) and 29.92 in. Hg (101.325 kPa) pressure. Vapors or gases are often expressed in parts per million (ppm) by volume or in mass per unit volume. Concentrations in ppm by volume can be converted to mass per unit volume values as follows:

- ppm × molecular weight/24,450 = mg/L
- ppm × molecular weight/0.02445 = μg/m³
- ppm × molecular weight/24.45 = mg/m³
- ppm × molecular weight × 28.3/24,450 = mg/ft³

TABLE B-2 Concentration of Interest for Selected Contaminants *(Continued)*

(Note: References numbers that are followed by [c] and [m] list the concentrations of interest [c] and measurement methods [m].)

TABLE 2.3.1 (Note: The user of any value in this table should take into account the purpose for which it was adopted and the means by which it was developed.)

Contaminant	Sources	Concentrations of Interest	Comments	References
Lead (Pb)	Paint dust Outdoor air	1.5 µg/m^3	Based on adverse effects on neuropsychological functioning of children, average exposure for three months (WHO: 0.5–1 µg/m^3 for 1 year). Sources—leaded gasoline (being phased out), paint (houses, cars), smelters (metal refineries), manufacture of lead storage batteries. Health effects—brain and other nervous system damage; children are at special risk. Some lead-containing chemicals cause cancer in animals. Lead causes digestive and other health problems. Environmental effects—Lead can harm wildlife.	B-4 [c] B-4 [m] B-18
Nitrogen Dioxide (NO_2)	Leaking vented combustion appliances Unvented combustion appliances Outdoor air Parking garages	100 µg/m^3	Based on providing protection against adverse respiratory effects, average exposure for one year.	B-4 [c] B-9 [m] B-18
			Sources—burning of gasoline, natural gas, coal, oil, etc. Cars are an important source of NO_2 outdoors and cooking and water- and space-heating devices are important sources indoors. Health effects—lung damage, illnesses of breathing passages and lungs (respiratory system). Environmental effects—Nitrogen dioxide is a component of acid rain (acid aerosols), which can damage trees and lakes. Acid aerosols can reduce visibility. Property damage—Acid aerosols can eat away stone used on buildings, statues, monuments, etc.	
		470 µg/m^3	24-hour average to prevent high exposures during use of combustion appliances such as space-heating devices and gas stoves.	B-41
Odors	Occupants VOC sources (including fungal sources such as mold) Cooking, food processing, sewage, biowaste facilities, etc.	Predicted (or measured) acceptability to 80% or more of occupants or visitors	CO_2 concentration can be used as a surrogate for occupant odors (odorous bioeffluents). See Appendix C for a discussion of indoor CO_2 levels and ventilation rates. For sources other than people, source control is recommended.	B-12, 24, 29, 30 [c] B-9 (CO_2), B-15 (odor) [m]
Ozone (O_3)	Electrostatic appliances Office machines Ozone generators Outdoor air	100 µg/m^3 (50 ppb)	Based on 25% increase in symptom exacerbations among adults or asthmatics (normal activity), eight-hour exposure (WHO); continuous exposure (FDA). Ozone present at levels below the concentration of interest may contribute to the degradation of indoor air quality directly and by reacting with other contaminants in the indoor space. Ground-level ozone is the principal component of smog. Sources—outdoors, from chemical reaction of pollutants, VOCs, and NO_x; indoors, from photocopiers, laser printers, ozone generators, electrostatic precipitators, and some other air cleaners. Health effects—breathing problems, reduced lung function, asthma, irritated eyes, stuffy nose, reduced resistance to colds and other infections. May speed up aging of lung tissue. Environmental effects—Outdoors, ozone can damage plants and trees; smog can cause reduced visibility. Property damage—Indoors and outdoors, ozone damages natural and synthetic rubbers, plastics, fabrics, etc.	B-6, 11 [c] B-6 [m] B-18
Particles ($PM_{2.5}$)	Combustion products, cooking, candles, incense, resuspension, outdoor air, diesel exhaust, and parking garages	15 µg/m^3		B-4

[a] The US EPA has promulgated a guideline value of 4 pCi/L indoor concentration. This is not a regulatory value but an action level where mitigation is recommended if the value is exceeded in long-term tests.

Conversion Factors[B-17]

Parts per million and mass per unit volume:

Measurements of indoor airborne concentrations of substances are generally converted to standard conditions of 77°F (25°C) and 29.92 in. Hg (101.325 kPa) pressure. Vapors or gases are often expressed in parts per million (ppm) by volume or in mass per unit volume. Concentrations in ppm by volume can be converted to mass per unit volume values as follows:

ppm × molecular weight/24,450 = mg/L
ppm × molecular weight/0.02445 = µg/m^3
ppm × molecular weight/24.45 = mg/m^3
ppm × molecular weight × 28.3/24,450 = mg/ft^3

TABLE B-2 Concentration of Interest for Selected Contaminants *(Continued)*

(Note: References numbers that are followed by [c] and [m] list the concentrations of interest [c] and measurement methods [m].)

TABLE 2.3.1 (Note: The user of any value in this table should take into account the purpose for which it was adopted and the means by which it was developed.)

Contaminant	Sources	Concentrations of Interest	Comments	References
Particles (PM_{10})	Dust Smoke Deteriorating materials Outdoor air	50 μg/m³	Based on protecting against respiratory morbidity in the general population and avoiding exacerbation of asthma, average exposure for one year, no carcinogens. Indoor concentrations are normally lower; guideline level may lead to unacceptable deposition of "dust."	B-4 [c] B-4 [m]
			Sources—burning of wood, diesel, and other fuels; industrial plants; agriculture (plowing, burning off fields); unpaved roads. Health effects—nose and throat irritation, lung damage, bronchitis, early death. Environmental effects—Particulates are the main source of haze that reduces visibility.	
			Property damage—Ashes, soot, smoke, and dust can dirty and discolor structures and other property, including clothes and furniture.	B-18
Radon (Rn)	Soil gas	4 pCi/L[a]	Based on lung cancer, average exposure for one year.	B-7 [c,m] B-10 [m]
Sulfur Dioxide (SO_2)	Unvented space heaters (kerosene) Outdoor air	80 μg/m³	Based on protecting against respiratory morbidity in the general population and avoiding exacerbation of asthma, average exposure for one year (WHO: 50 μg/m³ if with PM). Source—burning of coal and oil, especially high-sulfur coal from the eastern United States; industrial processes (paper, metals). Health effects—breathing problems; may cause permanent damage to lungs. Environmental effects—SO_2 is a component of acid rain (acid aerosols), which can damage trees and lakes. Acid aerosols can also reduce visibility. Property damage—Acid aerosols can eat away stone used in buildings, statues, monuments, etc.	B-4 [c] B-4 [m] B-18
Total Volatile Organic Compounds (TVOCs)	New building materials and furnishings Consumable products Maintenance materials Outdoor air	Precise guidance on TVOC concentrations cannot be given	A variety of definitions of TVOC have been employed in the past. Reference B-27 contains a specific definition that reflects recent thinking on the subject. There is insufficient evidence that TVOC measurements can be used to predict health or comfort effects. In addition, odor and irritation responses to organic compounds are highly variable. Furthermore, no single method currently in use measures all organic compounds that may be of interest. Therefore, some investigators have reported the total of all measured VOCs as the SumVOC in order to make explicit that the reported value does not represent the total of all VOCs present. Some of the references included here use this method for presenting VOC measurement results. Setting target concentrations for TVOCs is not recommended. Setting target concentrations for specific VOCs of concern is preferred.	B-9 [m] B-14, 26-28, 35, 37
Volatile Organic Compounds (VOCs) (See Table B-3 for a list of selected compounds)	New building materials and furnishings Consumable products Maintenance materials Outdoor air Parking garages Refueling stations	Must be determined for each individual compound (See Table B-3 for a list of selected compounds)	Individual volatile organic compounds may be contaminants of concern in the application of the IAQ Procedure. Concentrations of concern range from less than 1 part per billion (ppb) for some very toxic compounds or for compounds having very low odor thresholds up to concentrations several orders of magnitude higher. Not all compounds can be identified, and toxicological data are incomplete for many compounds.	B-22–26, 28, 42, 43, 44 [c] B-9, 10, 21 [m] B-11, 15, 36, 38, 39, 11

[a] The US EPA has promulgated a guideline value of 4 pCi/L indoor concentration. This is not a regulatory value but an action level where mitigation is recommended if the value is exceeded in long-term tests.

Conversion Factors[B-17]

Parts per million and mass per unit volume:

Measurements of indoor airborne concentrations of substances are generally converted to standard conditions of 77°F (25°C) and 29.92 in. Hg (101.325 kPa) pressure. Vapors or gases are often expressed in parts per million (ppm) by volume or in mass per unit volume. Concentrations in ppm by volume can be converted to mass per unit volume values as follows:

ppm × molecular weight/24,450 = mg/L
ppm × molecular weight/0.02445 = μg/m³
ppm × molecular weight/24.45 = mg/m³
ppm × molecular weight × 28.3/24,450 = mg/ft³

Guide for Using Table B-3

Table B-3 provides information that may be beneficial for designers who choose to comply with the Indoor Air Quality Procedure of this Standard. The VOCs included in the table were reported in published, peer-reviewed surveys conducted in office buildings and in new and existing residences in North America during the period 1990–2000.[B-42,B-43,B-45] Only those VOCs for which exposure guidelines for the general population have been developed by cognizant authorities are listed in Table B-3.

Reference Exposure Levels (RELs) are guidelines for acute, 8-hour and chronic inhalation exposures developed by California Office of Health Hazard Assessment (OEHHA). Minimal Risk Levels (MRLs) for hazardous substances are guidelines for acute, intermediate and chronic inhalation exposures developed by the Agency for Toxic Substances and Disease Registry (ATSDR). Factors for $\mu g/m^3$ to ppb concentration conversions are shown.

The table does not purport to represent (a) all possible chemicals found in nonindustrial indoor environments and (b) all concentration guidelines, standards, and regulatory limits. Published, peer-reviewed surveys conducted in office buildings and in new and existing residences in North America since 2000 may identify several more compounds, for some of which guidelines may be available from the cognizant authorities described above.

TABLE B-3 Concentrations of Interest for Selected Volatile Organic Compounds

Compound	CAS Number	Chemical Class[a]	Conversion Factor: $\mu g/m^3$ to ppb[b]	CA OEHHA REL[B-36]			ATSDR MRL[B-46]		
				Acute[c] ($\mu g/m^3$)	8-hr[d] ($\mu g/m^3$)	Chronic[e] ($\mu g/m^3$)	Acute[f] (ppb)	Intermediate[g] (ppb)	Chronic[h] (ppb)
Acetaldehyde	75-07-0	Ald	0.554	470	300	140			
Acrolein	107-02-8	Ald	0.436	2.5	0.7	0.35	3	0.4	
Acrylonitrile	107-13-1	Misc	0.460			5	100		
Benzene	71-43-2	Arom	0.313	1300		60	9	6	3
Bromomethane (Methyl bromide)	74-83-9	Halo	0.258				50	50	5
1,3-Butadiene	106-99-0	Alke	0.452			20			
2-Butanone	78-93-3	Ket	0.339	13,000					
2-Butoxyethanol	111-76-2	Gly	0.207				6000	3000	200
t-Butyl methyl ether (Methyl-*t*-butyl ether)	1634-04-4	Ethr	0.277			8000	2000	700	700
Carbon disulfide	75-15-0	Misc	0.321	6200		800			300
Carbon tetrachloride	56-23-5	Halo	0.159	1900		40		30	30
Chlorobenzene	108-90-7	ClAro	0.217			1000			
Chloroform	67-66-3	Halo	0.205	150		300	100	50	20

a. Alc = alcohol; Ethr = ether; Gly = glycol ether; Ket = ketone; Ald = aldehyde; Estr = acetates and other esters; Acid = carboxylic acid; Alka = alkane HC; Alke = alkene HC; Cycl = cyclic HC; Terp = terpene HC; Arom = aromatic HC; ClAro = chlorinated aromatic HC; Halo = halogenated aliphatic HC; Misc = miscellaneous category
b. Conversion factors from $\mu g/m^3$ to ppb
c. Exposure averaging time is 1 hour
d. Exposure averaging time is 8 hours and which may be repeated
e. Designed to address continuous exposures for up to a lifetime: the exposure metric used is the annual average exposure
f. Exposure to a chemical for a duration of 14 days or less, as specified in the toxicological profiles
g. Exposure to a chemical for a duration of 15–364 days, as specified in the toxicological profiles
h. Exposure to a chemical for 365 days or more, as specified in the toxicological profiles
i. See also Tables B-1 and B-2 for additional guidance on formaldehyde.

TABLE B-3 Concentrations of Interest for Selected Volatile Organic Compounds *(Continued)*

Compound	CAS Number	Chemical Class[a]	Conversion Factor: µg/m³ to ppb[b]	CA OEHHA REL[B-36]			ATSDR MRL[B-46]		
				Acute[c] (µg/m³)	8-hr[d] (µg/m³)	Chronic[e] (µg/m³)	Acute[f] (ppb)	Intermediate[g] (ppb)	Chronic[h] (ppb)
1,4-Dichlorobenzene	106-46-7	ClAro	0.166			800	2000	200	10
1,2-Dichloroethane (Ethylene dichloride)	107-06-2	Halo	0.247						600
Dichloromethane (Methylene chloride)	75-09-2	Halo	0.288	14,000		400	600	300	300
1,4-Dioxane	123-91-1	Ethr	0.278	3000		3000	2000	1000	1000
Ethylbenzene	100-41-4	Arom	0.230			2000	10,000	700	300
Ethylene glycol	107-21-1	Gly	0.394			400	788		
Formaldehyde[i]	50-00-0	Ald	0.815	55	9	9	40	30	8
n-Hexane	110-54-3	Alka	0.284			7000	600		
Naphthalene	91-20-3	Arom	0.191			9			0.7
Phenol	108-95-2	Alc	0.260	5800		200			
2-Propanol (Isopropanol)	67-63-0	Alc	0.407	3200		7000			
2-Propanone (Acetone)	67-64-1	Ket	0.421				26,000	13,000	13,000
Styrene	100-42-5	Arom	0.235	21,000		900	2000		200
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene)	127-18-4	Halo	0.147	20,000		35	200		40
Toluene	108-88-3	Arom	0.265	37,000		300	1000		80
1,1,1-Trichloroethane (Methyl chloroform)	71-55-6	Halo	0.183	68,000		1000	2000	700	
Trichloroethene (Trichloroethylene)	79-01-6	Halo	0.186			600	2000	100	
Vinyl chloride	75-01-4	Halo	0.391	180,000			500	30	
Xylene isomers	1330-20-7	Arom	0.230	22,000		700	2000	600	50

a. Alc = alcohol; Ethr = ether; Gly = glycol ether; Ket = ketone; Ald = aldehyde; Estr = acetates and other esters; Acid = carboxylic acid; Alka = alkane HC; Alke = alkene HC; Cycl = cyclic HC; Terp = terpene HC; Arom = aromatic HC; ClAro = chlorinated aromatic HC; Halo = halogenated aliphatic HC; Misc = miscellaneous category
b. Conversion factors from µg/m³ to ppb
c. Exposure averaging time is 1 hour
d. Exposure averaging time is 8 hours and which may be repeated
e. Designed to address continuous exposures for up to a lifetime: the exposure metric used is the annual average exposure
f. Exposure to a chemical for a duration of 14 days or less, as specified in the toxicological profiles
g. Exposure to a chemical for a duration of 15–364 days, as specified in the toxicological profiles
h. Exposure to a chemical for 365 days or more, as specified in the toxicological profiles
i. See also Tables B-1 and B-2 for additional guidance on formaldehyde.

APPENDIX J.

Initial Unit Test

Compounds that evaporate from many common housekeeping, maintenance, and building products made with organic chemicals. These vapors are released during used and storage. High levels of VOCs have been known to cause the following: eye, nose, and throat irritations,

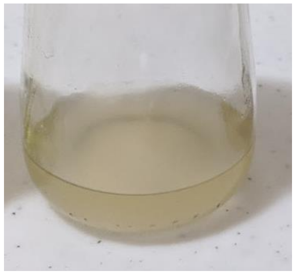
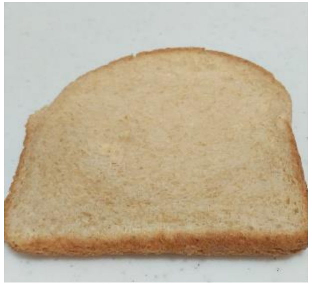
Baseline	Diluted Virgin Ammonia	Dirty Water & Ammonia	Diluted Cider Vinegar	Yeast Wheat Bread
Temperature: 18.77°C Humidity: 24.77 % Pressure: 96.87 kPa				
TVOC 68 ppb STD 7.019	TVOC 864 ppb STD 471	TVOC 1541 ppb STD 936	TVOC 23271 ppb STD 22464	TVOC 51120 ppb STD 16407
CO_2 400 ppm STD 0	CO_2 2028 ppm STD 784	CO_2 2997 ppm STD 1375	CO_2 6022 ppm STD 14444	CO_2 7006 ppm STD 9603
TVOC 22 ppb STD 1.187	TVOC 353 ppb STD 338	TVOC 1433 ppb STD 986	TVOC 2231 ppb STD 1624	TVOC 4140 ppb STD 2290
CO_2 548 ppm STD 7.37	CO_2 1568 ppm STD 350	CO_2 2292 ppm STD 518	CO_2 2705 ppm STD 764	CO_2 3598 ppm STD 1081

Table J-1 Indoor Air Quality sensor test [30]

TiO2 enhance UV-C			
30Min	Baseline	Bare Steel	TiO2 Coating
Start	14861	14883	14897
End	14839	14617	14631
% Change	0.14803849	1.787274071	1.785594415

Table J-2 Does TiO2 enhance UV-C [30]

Testing Sensor accuracy to online readings						
Date Time	UV Index	UVI reading	Accuracy	AQ Index	AQI reading	Accuracy
08 Feb 12:30	2	2.035 ±1.5%	98.280%	52	7.095 ±13.9%	13.644%
10 Feb 12:30	3.7	3.825 ±2.9%	96.732%	69	12.865 ±12.2%	18.645%

Table J-2 Testing VEML6075 Sensor, BME680 Sensor [27]

Integration Test

Sensor Integration Test

Time	UV-C microW/cm^2	Baseline SGP30 VOC ppb	Baseline SGP30 CO2 ppm	Baseline CCS811 VOC ppb	Baseline CCS811 CO2 ppm
8:12:00		4728	1844	2673	2950
8:14:00		5365	1908	2804	3013
8:16:00		5490	1907	2850	3032
8:18:00		5199	1937	2897	3054
8:20:00		5219	1935	2861	3039
8:22:00		5295	1966	2907	3060
8:24:00		5350	1943	2902	3056
8:26:00		5410	1953	2887	3051
8:28:00		5455	1958	2929	3069
8:30:00		5400	1933	2892	3053
8:32:00		5209	1957	2856	3037
8:34:00		5450	1983	2902	3058
8:36:00		5726	1964	2897	3054
8:38:00		5405	1969	2856	3037
8:40:00		5515	1982	2850	3032
8:42:00		5606	1971	2871	3042
8:44:00		5179	1933	2809	3012
8:46:00		5305	2017	2962	3057
8:48:00		5250	1964	2889	3072
8:50:00		5632	1984	2828	3016
8:52:00		5520	1941	2928	3038
8:54:00		5621	2048	2839	3047
8:56:00		5310	1963	2909	3030
8:58:00		5370	1851	2857	2912
9:00:00		5676	1906	2613	2981

Sensor Integration Test (cont.2)

Time	UV-C microW/cm^2	SGP30 VOC ppb	SGP30 CO2 ppm	CCS811 VOC ppb	CCS811 CO2 ppm
9:02:00	61.56	5069	1926	2637	2903
9:04:00	61.782	4949	1892	2595	2873
9:06:00	60.496	4733	1918	2581	2867
9:08:00	60.444	4502	1938	2613	2881
9:10:00	61.248	4497	1939	2559	2857
9:12:00	60.88	4628	1874	2548	2856
9:14:00	61.97	4527	1873	2541	2850
9:16:00	61.287	4252	1844	2530	2843
9:18:00	60.9	4382	1896	2485	2823
9:20:00	60.973	3981	1839	2474	2820
9:22:00	60.01	4277	1845	2541	2850
9:24:00	61.375	4031	1860	2489	2828
9:26:00	61.741	4096	1828	2480	2821
9:28:00	60.558	3394	1780	2370	2770
9:30:00	60.314	3700	1872	2428	2797
9:32:00	60.103	3885	1824	2421	2794
9:34:00	60.85	3529	1795	2410	2791
9:36:00	60.49	3700	1764	2404	2786
9:38:00	61.889	3314	1855	2388	2781
9:40:00	60.385	3514	1774	2416	2792
9:42:00	61.92	3349	1761	2370	2770
9:44:00	60.812	3529	1798	2399	2784
9:46:00	61.127	3459	1798	2387	2778
9:48:00	60.531	3414	1789	2376	2775
9:50:00	60.271	3404	1812	2337	2753
9:52:00	60.939	3264	1763	2326	2750
9:54:00	61.658	3108	1749	2354	2761
9:56:00	60.836	3168	1762	2308	2739

Sensor Integration Test (cont.3)

Time	UV-C microW/cm^2	SGP30 VOC ppb	SGP30 CO2 ppm	CCS811 VOC ppb	CCS811 CO2 ppm
9:58:00	61.236	3354	1731	2303	2737
10:00:00	61.134	3045	1692	2285	2730
10:02:00	61.651	3043	1749	2279	2725
10:04:00	60.174	3006	1702	2268	2722
10:06:00	60.575	3001	1704	2257	2715
10:08:00	60.367	2995	1713	2251	2715
10:10:00	61.763	3013	1741	2198	2695
10:12:00	61.182	3071	1734	2219	2704
10:14:00	61.393	3249	1693	2214	2702
10:16:00	61.616	3203	1712	2143	2672
10:18:00	61.586	3025	1684	2198	2695
10:20:00	61.788	3057	1715	2154	2679
10:22:00	60.192	3083	1697	2154	2674
10:24:00	60.478	3269	1730	2138	2667
10:26:00	60.578	3045	1795	2127	2664
10:28:00	61.772	3027	1685	2121	2659
10:30:00	61.17	2941	1727	2110	2657
10:32:00	60.569	3061	1758	2077	2636
10:34:00	60.782	3068	1807	2094	2643
10:36:00	61.782	3379	1747	2056	2628
10:38:00	60.618	3138	1773	2077	2636

Sensor Integration Test (cont.4)

Time	UV-C microW/cm^2	SGP30 False readings VOC ppb	SGP30 False reading CO2 ppm
10:26:00	60.578	3045	
10:28:00	61.772	3027	
10:30:00	61.17	2941	
10:32:00	60.569	3061	
10:34:00	60.782	3068	
10:36:00	61.782	3379	
10:38:00	60.618	3138	
10:40:00	61.558	3559	
10:42:00	61.329	3514	
10:44:00	60.861	3645	
10:46:00	60.396	3710	1848
10:48:00	60.985	3269	1838
10:50:00	60.745	3685	1841
10:52:00	60.853	3459	1821
10:54:00	60.833	4131	1967
10:56:00	60.986	4081	1933
10:58:00	60.339	4232	1999
11:00:00	60.304	4252	2014
11:02:00	61.129	4342	1975
11:04:00	61.936	4427	1977
11:06:00	60.612	5029	2246
11:08:00		4723	2251
11:10:00		4618	
11:12:00		4527	
11:14:00		4307	
11:16:00		4322	

Table J-4 Sensor Integration Test[30]

Acceptance Test